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Fertilizers.

B. H. Hite

WEST VIRGINIA
AGRICULTURAL EXPERIMENT STATION,
MORGANTOWN, W. VA.

J. H. STEWART, - - - Director

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...Fertilizers...

PART 1.

Sources and Composition.

B. H. HITE.

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INTRODUCTION.

The materials used by plants in the elaboration of their tissues are derived from the air, with the exception of a few parts in a hundred, which are obtained from the soil.

The carbon, which may constitute half of the dry matter of plants, is all derived from the four parts of carbonic acid gas in 10,000 parts of air. This quantity may appear small, but it is quite sufficient for all the vegetation the surface of the earth can produce, and it is continually being renewed. It is the form in which plants were evidently designed to take up their carbon, so there is no fault to be found with the source of this constituent, and no improvement to be offered.

Water, of course, is also obtained from the air, and as it is required by plants in quantities that are simply out of proportion to all other constituents combined, it must be regarded as the most important constituent of plant food. A part of the water that is absorbed by plants is broken down, and the hydrogen and oxygen (of which it is composed) united with carbon and other materials to form the complex tissues of plants.

Water is also the solvent of various materials within the plant and the carrier of the materials which the plant takes up from the soil. As such materials exist in very dilute solutions in the soil water, it is necessary that immense quantities of water be taken up by the plant. It has been estimated that at least 300 pounds of water are taken up by the roots of plants and evaporated from the leaves for every pound of dry matter formed. Many plants evaporate their weight of water every twenty-four hours.

In the naturally well watered sections, water usually receives about as much consideration as the carbonic acid gas, which is also furnished in abundance, gratis. It is only in the rainless regions, where agriculture is dependent upon irrigation, where water is measured and has to be paid for, that its importance as a plant food, etc., is really appreciated. Those dependent upon irrigation, however, have one decided advantage, in that they can apply the water just as it is needed and as a result are able to produce from soils, often no more fertile than the hillsides of this state, crops which we would regard as little less than phenominal, and this with a degree of certainty that is unknown to regions of rain and drouth.

In the elaboration of their tissues, plants require in all about a dozen different forms of matter. That these are not all required in the same proportion follows from what has already been said, but it does not follow that the materials required in small quantities may be slighted or that their place may be filled by other materials. The growth of a plant will be limited by a deficiency, or stopped by the absence of a single constituent of plant food; and this regardless of the quantity of the constituent required, or the abundance in which all other constituents may be present. The fertility of the soil, (other things being equal) is limited by the abundance of the least abundant constituent of plant food. The constituents derived from the soil include potash, soda, lime, magnesia, iron, alumnia, silica, nitrogen, phosphorus, sulphur, chlorine and maganese. Most of these materials are to be found in all ordinary soils, and in quantities that are practically inexhaustible. Three of these constituents, however, the nitrogen, phosphorus and potash, are usually present in the soil in smaller quantities, and being required by plants in larger quantities than some of the other constituents, they are more likely to become exhausted, and it is some one or more of these three constituents that

will need to be added to a soil, the fertility of which has fallen below par. Indeed, so rarely does a soil lack any other constituent, that fertilizers containing nitrogen, phosphorus and potash are known as "complete."

So about 95 per cent of the materials used in the construction of plants is furnished by the air. The remaining five per cent (or to be more accurate, one to ten per cent) is made up of eight or ten forms of matter derived from the soil, where two-thirds of this number will be found in abundance. It will often happen that a poor soil will only need some one or two of the three remaining materials likely to be deficient, and these will never be entirely wanting, even in the particular "forms" required by plants. So, in order to convert a poor soil into a fertile one it is only necessary as a rule, to supply a part of some one or two, or at most three, of the soil constituents. In other words, the farmer in the manufacture of his products never needs to consider more than a part of something like one partin a hundred of his raw materials; everything else is supplied gratis, or found in abundance at the factory.

The necessary nitrogen, phosphorus and potash, a part of which he may have to add to the soil will receive especial attention in the following pages.

POTASH.

Potash is always one of the most abundant constituents of plant ashes, so it is one of the materials which plants remove in largest quantities from the soil. Yet, soils, as a rule, are less likely to be deficient in potash than in phosphoric acid or nitrogen. Many of the rocks from which the soils are formed are fairly rich in potash, and in their disintegration yield it up to the soil. Indeed, some rocks contain so much potash that attempts have been made to use them as potash manures; for example, the volcanic rock pelagonite which doubtless, might be used, but for the abundance of other much more valuable forms of potash, to be mentioned presently. Certain varieties of the well-known mineral, felspar, from which the clays are derived, may contain as much as 16 per cent of potash. Clay soils, as a rule, are comparatively rich in potash, which doubtless contributes much to their well recognized "endurance."

Soils derived from mica and granite are also likely to be well supplied with potash, while sandy soils contain the least. But even a poor sandy soil will often contain as much as 0.10 per cent of potash, which is equal to something more than 3,000 pounds per acre, to the depth of only nine inches, while more fertile soils, and especially clay soils, may contain four or five times as much. In view of this enormous supply, it will be well to examine carefully the amount of potash removed from the soil by various crops, as shown in the following table :*

* Minn. Agric. Ex. Station Bull. No. 47.

	Lbs.
Wheat, 20 bushels	7
Straw, 2,000 pounds	28
Oats, 50 bushels	10
Straw, 3,000 pounds	35
Corn, 65 bushels	15
Stalks, 3,000 pounds	45
Peas, 30 bushels	22
Straw, 3,500 pounds	38
Mangels, 10 tons	150
Meadow hay, 1 ton	45
Clover hay, 2 tons	66
Potatoes, 150 bushels	75

The table shows that the grain crops remove the least potash; that the grasses require somewhat more than the grains, while root crops and in general, leafy crops, require the most. The table also shows that the potash is not uniformly distributed throughout the plant tissues, but tends to accumulate in certain parts, more particularly in the leaves and stems. Fortunately these are the parts which are most likely to find their way back to the soil, either directly or as farmyard manure.

But these quantities removed by crops are almost insignificent when compared with the quantities to be found in even the poorest soils, and it may well be asked why the addition of a few pounds of potash will so often produce such a marked increase in the crops, for it is hard to escape the conviction that the increase in yield must bear some relation to the increase in the amount of plant food at the disposal of the crop. The answer is to be found in the fact that the potash in the soil exists largely in the form of comparatively insoluble silicates, and other insoluble forms. These become available in time, and for this reason are valuable constituents of the soil, but it is a sort of prospective value,

so to speak, for so far as the immediate demands of the plant are concerned, they might as well consist of so much sand.

To determine with accuracy the amount of immediately available potash in the soil, is not as easy a matter as might be supposed, for it is not an easy matter working with small quantities in the laboratory during a brief period, to duplicate the action of soil water, plant roots, etc., in the field. Sufficiently accurate determinations have been made, however, to show that the available potash may be no more than one or two per cent of the total potash, or, in other words, instead of having thousands of pounds to the acre, as stated above, crops are really limited to hundreds and parts of a hundred pounds, in the light of which the quantities removed by various crops become a much more serious matter, while the apparently small quantities of readily available potash added as a fertilizer begin to assume proportions. They may indeed be a very respectable part of the total potash at the disposal of the crop.

The insoluble silicates, which contain so much of the soil's potash, must be broken down before the potash, or any other constituent, can be of any value to plants. This breaking down process is an extremely slow one, but it is continually going on, so a small part of these materials will always be in an advanced stage of decomposition, and while the potash may not be readily soluble in pure water, it is nevertheless so loosely held that it may be removed slowly by the soil water, and readily by the juices exuded by the roots of plants. After being deprived of their potash in this way, it would be reasonable to suppose that these silicates, (and other similar materials) might, if potash compounds in solution were presented, unite with the potash to form such materials as those just described, that is to say, silicates of potash, which, while not readily soluble in water, are readily available to plant

roots. This process, as a result of which soluble forms of potash are converted by the soil into less soluble forms, is known as the "fixation" of potash. That soils contain the necessary materials for accomplishing this "fixation," is evidently a matter of much importance, as otherwise the various immediately soluble forms of potash applied to the soil as fertilizers, would simply be carried about by the soil water, and if not used at once, would be carried away in the drainage water.

Clay soils and those naturally richest in potash, will contain in the greatest abundance the materials capable of effecting the "fixation" of potash, but it has been conclusively shown that even poor sandy soils can securely hold very much larger quantities of potash than are ever applied as a fertilizer.

Wood Ashes. In clearing the land of the original forests, the marked difference in the character of the vegetation on the spots where log heaps and brush piles were burned, could hardly escape the notice of even the most casual observer, and so the agricultural value of wood ashes came to be recognized long before the term potash was known to agriculture or chemistry.

Of course wood ashes contain all of the other mineral constituents of plants, but with the exception of the phosphoric acid and lime these are all found in abundance in the soil, and so can claim little credit for the results. Even the phosphoric acid is in an insoluble form, and the lime, although it may be present to the extent of 30 per cent, could claim little credit unless the ashes be applied in quantities involving an extravagent use of the potash. So the value of wood ashes depends very largely on the potash they contain. This is in the form of carbonate of potash (a compound of potash and carbonic acid). The carbonate of potash is undoubtedly one of the very best forms for agricultural purposes. It is a strongly alkaline substance, and may, like the carbonate of lime (which see), correct

acidity, promote nitrification, and even effect certain changes in the mechanical condition of the soil. The carbonate of potash might be present to the extent of 15 to 25 percent in pure unleached ashes. The product found on the market, however, is usually leached more or less and contaminated with dirt and other foreign materials, until the potash will be more accurately represented by something less than half of the minimum figure just mentioned, while if badly leached the potash may fall as low as one per cent. If such ashes were to be had at prices consistent with their use in large quantities, some benefit could be obtained from the lime. When used sparingly, however, as present prices demand (if, indeed, they are to be had at any price) these leached ashes will probably do little more than emphasize the fact already stated "that the value of wood ashes depends very largely on the potash they contain."

When wood was so largely used as fuel, wood ashes were a most excellent form of potash at a very reasonable price, but the replacement of wood by coal has made wood ashes very scarce, while the leaching and contamination with foreign materials makes their composition very uncertain, so that at present they are not only the most expensive form of potash, but as a rule the most unreliable.

For a long time plant ashes were the chief source of potash, not only for use in agriculture, but for all other purposes, and as the uses for potash rapidly increased, while wood became more and more scarce, it is not surprising that there should have been those who looked forward to what appeared to be an approaching scarcity of potash, or that it should have been suggested that certain plants, such as wormwood and tansy, which were known to be heavy feeders on potash, should be grown for the express purpose of extracting potash from the soil. Comment on such a practice is unnecessary, and yet we can hardly escape the conviction that a

short experience with what might be called a "wormwood and tansy" condition of agriculture, might have been of value in enabling farmers to appreciate some of the blessings which nature held in store, for it does not seem to have been intended that the soil should be robbed of its potash in order to meet the demands of the various industries.

A little of the potash, which during untold ages, had been leached out of the soil and carried away to the ocean, (the common receptacle for all soluble things), has been recovered and laid away against the day when potash in the soil would be scarce. As a result of some of the upheavels which have played such an important part in the history of the earth, an inland sea was formed which retained communication with the ocean through a number of small channels. The climate of that section, though temperate now, was tropical then, and the evaporation of the sea water flowing in through the channels from the ocean, proceeded rapidly, until, the deposits of potash and other materials on the bottom of the sea, was in some places, nearly a mile thick, when a layer of tough clay, impervious to water, was spread over the deposits, forever protecting them from loss by leaching. Other formations were deposited on top of the clay, and so these treasures lay buried for ages, until discovered by the nearest accident. "Early in the last century, the town of Strassfurt, in northern Germany, was noted for its extensive salt works, which employed only the old, unscientific pan process for evaporating water from a salty liquor or natural brine, which was obtained from driven salt wells. This method was slow, wasteful and relatively expensive, so that when deposits of rock salt were discovered in various places, this evaporated product could not hold its own against the competition of the mined crystal salt.

Thus, the famous Strassfurt works ceased to pay. In fact, as the salt markets then were, these works

were dead property, and, with the hope of turning them to some profit, the Prussian government began borings in 1839, expecting to find rock salt. This led to the sinking of a shaft, begun in 1852, which five years later struck rock salt, but not until it had passed through enough potash to supply the world until long after generations yet unborn will have ceased to have any interest in the matter.

The potash of the Strassfurt salts exists in two forms, the chloride, which is probably better known as muriate, and the sulphate. Both are readily available and securely fixed in the soil. There is a difference, however, in the diffusibility of the two forms, the chloride having the advantage in this respect, for experience shows that it will distribute itself through a larger volume of soil before becoming fixed. The importance of uniform distribution will receive attention in connection with soluble phosphates, (which see).

There is another difference between these two forms that demands more careful attention, and this has to do with their effect on certain crops. Sulphates, as a rule, are a valuable addition to the soil, and the sulphate of potash may be used indiscriminately on any and all crops; but the same is not true of the chloride of potash, for while this may be depended upon to produce a corresponding increase in the yields, it is likely to injure the quality of certain crops, and these, unfortunately, are among the crops requiring potash in the largest quantity. The chloride of potash injures the burning qualities of tobacco, and as the value of tobacco depends so largely upon this quality, the chloride of potash should never be used on this crop.

The chloride of potash will give to potatoes a waxy consistency and like stable manure, increase the impurities and lower the sugar content of sugar beets; so it is the sulphate of potash that should be used on these crops. On the great majority of crops, as grains and grasses, it makes little or no difference which form is

used, and the chloride being the cheaper may often be used to advantage; in fact, there are cases in which it even gives better results than the sulphate, e. g. on hemp and certain other fibre plants, where it tends to lenghten and toughen the fibre.

When the chloride of potash is applied to the soil, the potash becomes fixed, the chlorine with which the potash was combined, being left to combine with some other constituent of the soil, usually lime to form chloride of lime. This chloride of lime, or calcium chloride, is very injurious to the rootlets of young plants, but it is an extremely soluble material, and the soil has no power to hold it, so it is quickly leached out in the drainage water. This suggests a method of using the chloride of potash that would avoid much of the injurious effects; apply it as long as possible before the crop is planted. If applied in the fall, the winter rains may be depended upon to either wash out the chlorides or carry them so far into the lower layers of the soil that they will be out of the reach of young plants beginning their growth in the spring. It should be distinctly understood that the differences above referred to are not due to any difference in the actual potash (which is one and the same thing in both forms, and the world over) but to the materials with which the potash is associated. When the potash becomes fixed in the soil it parts company with these materials to unite with the silicates etc., as already described, and from what has been said it would seem to follow, also, that in uniting with the silicates, the various forms of potash applied to the soil as fertilizers must be converted into forms very similar indeed to the quickly available potash already in the soil. We mention this fact in view of a prevailing impression that commercial or "artificial" fertillzers feed the plant (if indeed they do not simply stimulate it) in some unnatural way, while, as a matter of fact, the various forms of potash, (and as we shall presently see, of phosphoric acid and nitrogen also), when applied

as fertilizers are quickly converted by the soil into just such forms as those from which plants have been obtaining these constituents ever since plants existed on the earth. A part of the potash found on the market is in the form of chloride of potash, which is the cheapest form of potash available at the present time. On certain crops chlorides are injurious and we have tried to show how the injurious effect of chlorides (not of potash) may be avoided.

Kainit is doubtless the best known of the crude Strassfurt salts. It contains about 12.5 per cent of actual potash, practically all of which is in the form of sulphate. It also contains large quantities of chloride of soda (common salt) and chloride and sulphate of magnesia, so, notwithstanding the fact that the potash is in the form of sulphate, the large excess of chlorides with which it is associated, causes Kainit to act very much like the chloride of potash, and the same precautions should be observed in using it. (See Magnesia).

Quite a little common salt is shipped into the state every year for agricultural purposes, so there are doubtless those who attach some agricultural value to the material. In view of the fancy prices that are often obtained for salt, it would certainly be much better to use Kainit, which contains an abundance of salt, and also contains something that the soil may need. The relatively large amount of common salt, chloride of magnesia, etc., in Kainit, greatly increases the cost of handling and shipping, so that the potash it contains is likely to cost considerably more, pound for pound, than in the more concentrated products.

Silvinit is another crude product, similar to Kainit, in that it contains large quantities of common salt, chloride of magnesia, etc. The actual potash, which is in the form of chloride and sulphate, will average about 16 per cent. In this country it has not been used to the same extent as Kainit.

Muriate of Potash. Of the manufactured products, muriate (chloride) of potash is the most generally used. Several grades of this material are to be found on the market, some of them running as high as 98 per cent chloride of potash. The most popular grade in this country is about 80 per cent pure, and contains about 50 per cent actual potash.

It will be observed that there are just about four times as much actual potash in this high grade muriate as in Kainit, and notwithstanding the marked difference in price, a little figuring (including freight rates, etc.) will show that the muriate is much the cheaper form. It is also to be observed that in using the high grade muriate (although this is almost pure chloride of potash) a smaller amount of chlorides will be applied to the soil than if the same amount of potash in the form Kainit be used. The muriate is the cheapest form of potash on the market today, and for the great majority of crops (and with the simple precautions already mentioned) it is for most purposes all that could be asked in the way of a potash fertilizer.

High Grade Sulphate of Potash is usually sold on a purity basis of 98 per cent, or an equivalent of 53 per cent actual potash. It is used extensively in the manufacture of commercial fertilizers, and is undoubtedly the best form of potash for agricultural purposes obtainable at the present time. It is to be preferred to the muriate because it can be used on any crop at any time. It is one of the most expensive forms of potash, and yet, the prices often paid for Kainit would purchase an equivalent amount of potash in the form of high grade sulphate.

Strassfurt Salts On Acid Soils. We have seen that when the chloride (muriate) of potash is applied to the soil, a corresponding amount of lime (in the form of the very soluble chloride of lime) is removed from the soil, and somewhat similarly, when the sulphate of potash is

used, the sulphate of lime (gypsum) is formed. This being much less soluble, is not removed, and is really a valuable addition to the soil, but it is formed at the expense of the carbonate of lime, which is the soil's principal protection against acidity. We shall frequently have to speak of an acid condition of the soil, which is so unfavorable to the great majority of crops and which is due to a lack of sufficient alkaline or basic constituents, such as lime. We shall also have to call attention to a number of manurial substances which, by drawing heavily upon the lime content of the soil, tend to aggravate any existing tendency towards an acid condition, and while in a state like West Virginia, with limestone in almost every other hillside, in some cases a hundred feet thick, there can not be so much as a ghost of an excuse for permitting a soil to get in such a condition, it may be well in this connection to call attention to the fact that if the best results are to be obtained from the use of Strassfurt Salts, it is necessary that the soil be not lacking in lime. So, we have one, and possibly two simple precautions to be observed in using Strassfurt Salts: (1) Be sure that the soil is not lacking in lime, and (2) if the muriate, or any of the crude products (rich in chlorides) are to be used, apply some time before the crop is planted.

The Strassfurt Potash salts will receive attention again in connection with "Lime on soils containing an excess of magnesia." In this connection it will be sufficient to add that these potash salts are quite capable of meeting every demand of the soil for potash, and that when they are applied to a soil deficient in potash and fail to bring reasonable returns the trouble is due to a lack of lime or to some other abnormal condition of the soil, not to the potash salts.

PHOSPHORIC ACID.

A few kinds of rock, such as appatite, phosphorite, etc., are very rich in phosphoric acid, and will receive attention presently; but the rocks from which the soils are derived, contain it in almost trifling quantities. Even in fertile soils it rarely exceeds two-tenths of one per cent. There are cases, to be sure, in which it will reach three or four tenths, or even six-tenths, as in the case of the famous Russian black earth, but these are rare exceptions. In fact, one-tenth of one per cent, which, as we have seen, amounts to over 3,000 pounds per acre to the depth of nine inches, is probably a fair estimate for a great majority of fairly fertile soils.

Condition in which Phosphoric Acid Exists in the Soil. In the rocks from which the soils are derived, the phosphoric acid exists largely in combination with lime, as phosphate of lime. It also exists in combination with iron and alumina. A very considerable part of the phosphoric acid may be contained in the small, but yet undecomposed fragments of the original rocks, and even when these are decomposed the same forms prevail, *i.e.* phosphates of lime, iron and alumina.

The phosphate of lime is practically insoluble in water, and but very slightly soluble in the soil water. It has a tendency in the presence of the large quantities of iron and alumina in the soil to exchange its lime for these and so pass to a phosphate of iron and alumina, which is even less soluble than the phosphate of lime. All of these become available in time. A certain amount of phosphoric acid will be associated with the remains of previous crops, and will become available as

these decompose. Such decompositions undoubtedly aid in rendering other inert forms of phosphoric acid available, but this is a slow process at best, and no more than a mere fraction of the total phosphoric acid in the soil is available at any one time. It is, of course rapid enough, or even more rapid than is necessary for the original forests or prairies, for in such cases there is an accumulation of more readily available phosphates (and other elements of plant food) in the readily decomposible vegetable remains. It is an altogether different matter, however, when everything that the soil can produce is forever removed. The elements of fertility stored up in the vegetable remains during the long periods of the most favorable conditions, are quickly exhausted, after which there is abundant opportunity to observe the rate at which the original inert mineral phosphates and other mineral constituents of the soil become available, as evidenced by the quantities that may be removed by the crops. The process is so slow that many practical farmers endeavor to return to the soil at least as much phosphoric acid as is removed by the crops.

Amount of Phosphoric Acid Removed by Various Crops.

	Pounds removed from one acre.
Wheat, 20 bushels	12.5
Straw, 2,000 pounds	7.5
Oats, 50 bushels	12.0
Straw, 3,000 pounds	6.0
Corn, 65 bushels	18
Stalks, 4,000 pounds	4
Peas, 3,500 pounds	25
Clover, 4,000 pounds	28
Potatoes, 150 bushels	20

It will be observed that while the crops referred to require, as a rule, somewhat smaller quantities of phos-

phoric acid than of potash, they nevertheless remove a much larger part of the soil's total supply, and while potash finds its way largely to those parts of the plants that are most likely to be returned to the soil, the, phosphoric acid tends to accumulate in the seeds, or the parts usually sold off the farm. It is not a difficult matter, therefore, to understand why the store of available phosphates in new lands may be quickly exhausted, or why so many soils respond so gratefully to even light appications of phosphoric acid in some readily available form.

Another point demanding attention in this connection is that plants take up by far the greater part of their phosphoric acid during the usually brief period of maximum growth, and it is for this reason, doubtless, that quick growing crops are benefited so much by an application of readily available phosphoric acid, even on soils that contain an abundance of this constituent in the form of animal or vetegable matter which must have time to decompose.

Phosphate Deposits. In speaking of the scarcity of phosphoric acid in the rocks from which soils are usually derived, attention was called to the fact that there are in many parts of the world extensive formations that are very rich in this constituent. Such formations are found in South Carolina, North Carolina, Florida, Virginia, Tennessee, Canada, Belgium, France and other places. In these deposits the phosphoric acid exists in combination with lime in the proportion of one part of phosphoric acid to three parts of lime. This is the same form in which phosphoric acid exists in other rocks and in the soil. In the formations referred to it is never found pure, but always associated with more or less other earthy matter. The amount of impurities varies in the different deposits named, from fifteen to sixty-five per cent. The phosphate rocks mined in this country usually contain from sixty to eighty per cent of calcium phosphate. This, as we have seen, is insoluble

in pure water, and but very slightly soluble in soil water, so there is no reason for believing it to be any more readily available than the inert forms existing in the soil. However, it is sometimes ground to a fine powder, known as "floats" and used directly as a fertilizer. When used on certain soils for certain crops and under certain conditions, results have been obtained which are said to merit more attention than they usually receive, but the conditions most favorable for "floats" are not, as a rule, those most to be desired. For example they have been recommended for use on wet, heavy acid soils, heavily charged with organic matter. It would certainly be much better to drain such soils, give them an application of lime, and if they need phosphoric acid, apply it in some more readily available form. Floats are, of course, much cheaper than acid phosphates, and as nothing has been added to them to make the phosphoric acid available, they contain a great deal more phosphoric acid; in a word, the same amount of money will buy a great deal more phosphoric acid (such as it is) in the form of floats, than in the form of an acid phosphate. Semi-occasionally somebody discovers this fact and proposes to economize by applying large quantities of floats. The proposition has always possessed a peculiar fascination for those who believes in feeding the soil instead of the crop, but suffice it to say that farmers have long since settled the matter, and most emphatically in favor of the soluble phosphates.

Bones. Among the materials that have been used to make good the deficiency of phosphoric acid in the soils, bones deserves a conspicuous place. They are among the oldest of manures, "and like guano, though to a less extent, the early practice of using bones did much to arouse an interest in the problems of manuring, and to bring home to farmers the principles underlying that practice. It was from bones that Liebig first made superphosphate of lime, and it was the favorable action of the bones on the turnip crop that first drew the atten-

tion of Sir John Bennett Lawes to the subject of artificial manures."

Bones consist of an organic and inorganic part. These completely interpenetrate each other, so that when either is removed the remaining part retains the original shape of the bone. The organic part may be removed by strong heating—the inorganic part by means of dilute acids. The organic part is composed largely of a substance called ossein, which is rich in nitrogen, and which on being boiled for a long time is converted into geletine. The inorganic part consists principally of phosphate of lime, with small quantities of phosphate of magnesia, carbonate of lime and fluoride of calcium. Raw bones contain on an average about 29 per cent of phosphoric acid, and 6 per cent of nitrogen. The composition of bones varies considerably with the age and kind of animal and the part of the skeleton to which they belong. In a general way it may be said that the older the animal and the harder the bone, the richer it will be in phosphoric acid and the poorer in nitrogen. The variations in the bones as found on the market for agricultural purposes are due largely to the treatment they have received at the hands of the manufacturer.

Steamed Bones. Bones are steamed for the purpose of extracting gelatine and glue. This practice, of course, removes a part of the nitrogen, but it increases the percentage of phosphoric acid, and removes the worthless fatty materials, which by preventing the access of air and moisture interfere with the decomposition of the raw bone in the soil. Experience shows that steamed bones act more quickly and are, consequently, a more valuable manure than the raw bones, so manufacturers frequently steam them more or less for this purpose alone. Indeed, there is comparatively little raw bone to be found on the market.

Another method for removing the fat, which has the advantage of not removing the nitrogenous materials, consists in extracting the bones with benzine, but the

method is more expensive and has not come into general use, as it has been found that the bones thus treated do not decompose as readily as the steamed bones.

Bone Tankage is the material remaining in the large tanks in connection with the slaughtering establishments, for boiling cattle heads, hoofs, clippings and refuse animal matter generally, in order to remove certain constituents. A number of grades are found on the market, varying in phosphoric acid from 10 to 20 per cent. These materials are all rich in nitrogen, which in a general way may be said to increase as the phosphoric acid decreases. The composition of some varieties of tankage approaches that of bone, and in as much as it has been thoroughly boiled, its action will approach that of steamed bones. Much will depend upon the degree of fineness to which it is ground, and this is true of all bone manures.

Action of Bones. Before the phosphoric acid or any other constitutent of bones or any animal tissue can serve as a food for plants they must undergo decomposition. In dissolved bones (to be considered presently) the decomposition is effected at the factory by well known chemical methods, but the decomposition of the untreated bones must be accomplished in the soil. The phosphoric acid in the bones exists in the form of the "insoluble" or "tricalcic" phosphate. In speaking of this material as it exists in the soil, the fact was mentioned that decomposing organic matter may hasten the conversion of these insoluble materials into more readily available forms. The phosphate of lime in bones is very intimately mixed with a large amount of readily decomposable organic matter. It is also in a very spongy or finely divided condition, exposing a large amount of surface to the solvent materials formed as the organic portion decomposes. But for this finely divided condition and intimate association with the organic matter, there is no reason to believe that the

phosphate of lime in bones would be any more readily available than that in the phosphate deposits; indeed, the latter are supposed by many to be derived from the bones of prehistoric animals, a theory that is supported by the presence of an abundance of shark's teeth and other fossil remains, which, by the way, first directed attention to the Charleston deposits.

Fine Ground Bone. The fineness of subdivision is one of the most important matters connected with the subject of availability of phosphatic manures. The finer the particles the more surface there is exposed to the action of the soil water. "A hundred or more years ago when bones first began to be used in England, they were applied either unbroken, or later in course fragments, at the rate of ten or twelve hundred pounds to the acre. Afterwards, when bone meal came to be manufactured, six or seven hundred pounds of the meal per acre were deemed a sufficient dose, while later one or two hundred pounds of superphosphate [in which, as we shall see, a state of subdivision is reached that would be impossible by grinding] were found to produce the same effect on the same soils and and crops"* and with greater certainty. When the superiority of bone meal over coarser bone came to be appreciated, attempts were made to grind the bones still finer. It was then considered advisable to use raw bones, and certain difficulties were encountered in that the grease would lubricate the grinding surfaces. But Yankee ingenuity was not to be dismayed by a little obstacle like this, and a machine was produced which by whirling the bones together made them act as their own grinding surfaces, and reduced them to a powder so fine that it would float in the air like flour, so that in apply ing it to the fields much of it was carried away by the winds. For this, and other reasons, this "floated bone" has not come into general use. It is interesting to note, however, that it decomposed so readily that it had to be

* Agriculture, Storer.

salted to keep it from spoiling before it could be used. So, for practical purposes, at least, there seems to be a limit to the fineness to which bones should be ground.

So far, we have considered briefly the effects of different methods of preparing bones upon the availability of the phosphoric acid which they contain. It should be observed, however, that the decompositions upon which the availability depends, take place in the soil which may also exert a marked influence. Air and moisture are necessary, and while, for example, a heavy wet soil would provide the moisture, it would also exclude the air, and just the reverse is true of a light dry soil. From this it may be suspected that it is upon medium soils, that are neither too wet or too dry that bones give the best results and experience has shown that this is true. Even under the most favorable conditions, however, bones must be considered as a slow acting manure. The effect of an application of bones is noticeable for several years, and while this effect is usually much prized and is a matter of much importance in the direction of soil improvement, it also shows how much time is required for the complete decomposition of the bones, and (in view of the uncertainties often attending such decompositions,) the advantage of using the more readily available forms of phosphoric acid for quick growing crops, which must be able to obtain this element during a very short period. For slower growing crops, such as orchards and permanent pastures and with a view to the improvment of the soil bones are an ideal source of phosphoric acid and nitrogen, and have won a place in agriculture which they will doubtless hold for many a year.

Bone Black is used in enormous quantities for clarifying sugar. It is prepared by heating bones in air-tight vessels until all volatile matter is driven off. The remaining product, which retains, in part, the original shape of the bones, consists of the phosphates and other earthly constituents of the bones and a certain amount

of very finely divided charcoal. It is this charcoal which effects the removal of the coloring matters and other impurities from the solutions of crude sugar. Ordinary charcoal possesses the same properties, but to a much more limited extent, because in the bone black the charcoal is not only in an extremely fine condition, but is uniformly distributed over the porous earthy framework of the bones, and exposes an immense surface to the action of the sugar solution. In will be remembered that it is this same surface which is exposed to the attacks of the various solvents formed in the course of the decomposition of the organic matter with which the pores were originally filled, and which is so largely responsible for the availability of the bones. After the bone black has lost its power to remove impurities, it is used in the manufacture of superphosphates. It is a most excellent material for this purpose, as it contains about thirty per cent, or more, of phosphoric acid, and very little objectionable materials, such as oxide of iron and alumina.

Before the introduction of superphosphates, bone black was used directly as a fertilizer and was held in high esteem especially in France, and for the buckwheat crop. It is rarely used at present, and must be regarded as a very slow acting manure. The organic matter which plays such an important part in the decomposition of bones is not only absent, but it is replaced by a coating of charcoal which not only refuses to ferment, but may even protect the mineral matter of the bone. Notwithstanding these facts, the bone black is undoubtedly more readily available than the untreated ground phosphate rock. Indeed the efficiency of bone black and ordinary charcoal in removing coloring matters, etc., and the difference in the availability of bone black and floats have features in common, but these follow immediately from what has already been said.

Bone Ash is still a small, but not to be overlooked source of phosphoric acid, as it is still imported, principally from South America. In order to reduce the weight and costs of handling, the bones are burned in the open air, which drives off all nitrogenous and other organic matter. No one thinks of using such materials for agricultural purposes until they have been converted into superphosphates.

Superphosphate. So far we have had to deal with phosphatic materials in their natural forms. In every case the phosphoric acid existed in the form of the insoluble phosphate of lime, or the less soluble phosphate of iron and alumina. We have found that the size and compactness of the particles, the association with organic matter, the condition of the soil, etc., exert a marked influence upon the availibility of these insoluble phosphates, but that even under the most favorable conditions they must be regarded as slow acting manures,—some of them extremely slow.

The insoluble or tricalcic phosphate, so often referred to, is a perfectly definite chemical compound, consisting of one part of phosphoric acid, united with three parts of lime, and may be represented in this way:

$$\left.\begin{matrix}\text{Lime}\\ \text{Lime}\\ \text{Lime}\end{matrix}\right\} \text{Phosphoric Acid.}$$

The properties of this substance are just as well known as those of common salt, and conspicuous among them, is its insolubility in water.

Phosphoric acid will combine with lime in several other proportions to form as many perfectly definite substances, but all of these are more soluble in water than the tricalcic phosphate. For example, it will unite with one part of lime to form what is called the "mono" (one) calcic (lime) phosphate, and this material is imme-

diately soluble in water. It is often represented as follows:

$$\left.\begin{matrix}\text{Lime}\\ \text{Water}\\ \text{Water}\end{matrix}\right\} \text{Phosphoric Acid.}$$

It will be observed that this soluble phosphate of lime differs from the insoluble phosphate only in that two parts of lime have been removed and two parts of water put in their place. It would appear, therefore, that in order to convert the insoluble phosphate of lime into the soluble form, it should only be necessary to treat it with the proper amount of some material which would readily exchange water for lime; and such is the case. Sulphuric acid (oil of vitrol) readily combines with one part of lime to form sulphate of lime, which is also known as gypsum or land plaster. So by treating one part of the insoluble phosphate of lime with two parts of sulphuric acid two parts of lime are removed to form gypsum, and there remains one part of lime united with one part of phosphoric acid, or the soluble phosphate of lime. These are, in brief, the principles involved in the manufacture of soluble phosphates, as discovered by Liebig sixty years ago, and in active use ever since. The practical application of this method, however, is by no means as simple as might be inferred from the above. The various sources of the insoluble phosphate, such as bone, bone black, phosphate rock, etc., are never pure, but are always associated with more or less other materials, such as phosphate of magnesia and carbonate of lime, iron, alumina; ete., which will also react with the sulphuric acid to form sulphates of magnesia, lime, iron, alumina, etc. The proportion of these impurities will vary in different samples, and as a given amount of no two of them will consume the same quantity of sulphuric acid, it may be suspected that the problem of determining the proper amount of sulphuric acid to satisfy the impurities and remove the proper amount of lime

from the tricalcic phosphate present, which, of course, will also vary, may be just a little more complicated than some representatives of the home mixing propaganda would have us believe.

In order that the action of the acid may be rapid and complete the phosphatic materials are ground to a fine powder, placed in a large revolving pan provided with automatic mixers, and the requisite amount of acid added. The reaction is very energetic, and in a minute or two the contents of the pan is converted into a frothy liquid, which, when the action subsides, is drawn off and allowed to dry. In the course of a few days it "sets," so that before it is ready for use it must again be reduced to a powder.

The Reverted Phosphate of Lime. We have seen that two parts of sulphuric acid will remove two parts of lime from the tricalcic phosphate, and as might be supposed, one part of sulphuric acid will remove one part of lime. This leaves two parts of lime united with one part of phosphoric acid, and the substance is known as dicalcic phosphate (two-lime-phosphate), and may be represented thus:

$$\left.\begin{matrix}\text{Lime}\\ \text{Lime}\\ \text{Water}\end{matrix}\right\} \text{Phosphoric Acid.}$$

This material is not soluble in pure water, but it does dissolve fairly well in soil water, and readily in the acid juices exuded from the roots of plants, so it must be regarded as available.

Now, this dicalcic phosphate is also formed when the soluble phosphate is allowed to act on the insoluble phosphate. In this change the soluble phosphate, which contains one part of lime, takes up one part of lime from the insoluble phosphate, which contains three: thus,

$$\left.\begin{matrix}\text{Lime}\\ \text{Water}\\ \text{Water}\end{matrix}\right\}\text{Phosphoric acid, and}\left.\begin{matrix}\text{Lime}\\ \text{Lime}\\ \text{Lime}\end{matrix}\right\}\text{Phosphoric acid,}$$

give

$$\left.\begin{matrix}\text{Lime}\\ \text{Lime}\\ \text{Water}\end{matrix}\right\}\text{Phosphoric acid, and}\left.\begin{matrix}\text{Lime}\\ \text{Lime}\\ \text{Water}\end{matrix}\right\}\text{Phosphoric acid.}$$

This change takes place in superphosphates, especially on long standing, and some of the soluble phosphate passes back or "reverts" to the less soluble dicalcic phosphate. It is for this reason that the dicalcic phosphate is generally known as the "reverted" phosphate.

It is obvious that if the soluble phosphate of lime should take up another part of lime from any other source it would be converted into the same reverted or dicalcic phosphate, and such a change takes place when the soluble phosphate is applied to the soil. The soluble phosphate also reacts with certain compounds of iron and alumina to form reverted phosphates of iron and alumina; but these changes are not so easily followed, and are to be regarded as objectionable for the products are far less readily available than the corresponding compounds of lime. Manufacturers avoid this sort of reversion by using only those phosphatic materials that are comparatively free from iron and alumina. It would seem that farmers might avoid them to some extent by making sure that their soils are not deficient in lime.

A superphosphate necessarily consists of a mixture of the soluble, insoluble and reverted phosphates of lime and the sulphate of lime or gypsum. In stating the composition of the superphosphates it is customary to speak of soluble, insoluble and reverted *phosphoric acid*. These terms are simply used for the sake of convenience, and refer to the actual phosphoric acid existing in the various forms of combination. For example, "10 per cent soluble phosphoric acid," means that every hundred pounds of the superphosphate referred to con-

tains ten pounds of actual phosphoric acid, and that this is in the soluble form, or in combination with lime in the proportion of one part of phosphoric acid to one part of lime.

Dissolved Rock Phosphates. By far the greater part of the immense quantities of superphosphates now in use are made from the phosphate rock already referred to. These have the advantage of being comparatively cheap, and as they contain an abundance of the one essential constituent, tricalcic phosphate, they are most excellent materials for this purpose. The composition of the rock phosphates from the various deposits mentioned varies considerably, so the superphosphates must also vary. Those made from the South Carolina rock usually contain about 14 per cent of available phosphoric acid; those from certain grades of Florida deposits contain 16 to 17 per cent, while those made from the richest Tennessee rock contain as high as 18 per cent.

Dissolved Bone Phosphates were the first superphosphates manufactured. The phosphate deposits had not been discovered and bones, bone black, etc., were the only suitable materials obtainable. The superiority of the dissolved bones over the untreated bone meal, etc., was soon established, and it won a place in the confidence of the farmers that it holds even to the present day. Bones are rich in tricalcic phosphate. Sulphuric acid will always convert this into the soluble phosphate, so bones are an excellent material for the manufacture of superphosphates. In addition to the tricalcic phosphate, bone contains a large amount of nitrogenous material, so superphosphates made from bone contain nitrogen, which adds much to their value. Indeed, where phosphoric acid and nitrogen are both needed, dissolved bone is one of the very best forms in which these constituents could be applied. Dissolved bones, however, are really ammoniated superphosphates, and to compare these with plain superphosphates would be very unfair; so, it will be better to confine our attention for

the present to the phosphoric acid in dissolved bones, and what is said will apply equally as well to dissolved bone black, which, of course, contains no nitrogen.

The well deserved popularity of bones, which were for so long the most valuable phosphatic manure, is probably responsible for the prevailing belief that dissolved bones and dissolved bone black possess something in common with bone manures generally, and that for this reason they are much to be preferred to the dissolved phosphate rock. In one form or another this notion turns up so often that a word in this connection may not be out of place.

We have tried to show how the intimate association with organic matter and certain differences in texture gives the insoluble phosphate of lime in bones an immense advantage over the same material in ground phosphate rock or floats, but such differences disappear on treating the materials with sulphuric acid, and, in the new substance formed all records of previous conditions and associations are forever lost. By no method under heaven or among men could any difference be detected between the soluble phosphate of lime prepared from bones, and that prepared from phosphate rock or from any other material. Its composition is as constant as anything in all nature. It is one and the same thing always. As ordinarily prepared in superphosphates from the various phosphatic materials, it is, of course, mixed with the various impurities which these materials contain, but from these it has nothing to gain as it is already more soluble than any other form into which it could be converted. As a source of soluble phosphates, therefore, there is nothing to be gained by using bones, and in view of the fact that these are so much more expensive than the phosphate rock, and that their action in their natural form possesses characteristics of value for many crops, it might seem to savor just a little of extravagance to use them for this purpose, but we shall presently have to call attention to

the fact that the treatment with sulphuric acid affects a marked improvement in the nitrogenous matter of the bones, so that all things considered the practice of dissolving bones is doubtless justifiable.

One other point: there are those who never miss an opportunity to urge, either directly or by implication, that the effect of dissolved bones and dissolved bone black is altogether different from that of the dissolved phosphate rock. The impression seems to be that the former made from bones, is, of course, a perfectly safe material to use, while the latter, being made from "acids" and "minerals" will "parch" and otherwise injurously effect the soil. It is hoped that what has been said in regard to the methods of manufacturing superphosphates will be sufficient to show that the only place for such differences is in the imagination of those who still manage to get about so much a line for catering to predjudices of this sort. There is no reason why either material should have any injurious effect; indeed, there are good reasons why the reverse should be true. As a source of available phosphoric acid, there is nothing any better than a plain acid phosphate made from phosphate rock.

Double Superphosphate. So far we have had to speak of "acid phosphates," "dissolved bone phosphates," "dissolved S. C. phosphates," "rock phosphates," etc., all of which terms and a number of others are often used indiscriminately. We have seen that the amount of available phosphoric acid in superphosphates depends upon the amount of impurities in the bone or rock from which they are made, and may vary from twelve to eighteen per cent. In order to make a more concentrated product, the following method is used, though not so extensively in this country as in Europe. A quantity of phosphate rock is treated with sulphuric acid, as already described, except that enough of the acid is used to remove all of the lime in the tricalcic

phosphate, leaving only the phosphoric acid; thus,

lime, lime, lime } Phosphoric acid and sulphuric acid, sulphuric acid, sulphuric acid

Sulphate of lime
give Sulphate of lime and phosphoric acid.
Sulphate of lime

The free phosphoric acid obtained in this way is immediately soluble in water, so together with any excess of sulphuric acid that may have been used it is washed out of the mass of gypsum and impurities of the original rock, and used to treat a quantity of high grade phosphate rock, when, it is evident, if two parts of the phosphoric acid to one part of tricalcic phosphate are used, the material formed must consist of one part of phosphoric acid to one part of lime, or in other words, it will be the soluble phosphate of lime. As no gypsum is formed in this case (except as a result of the slight excess of sulphuric acid used in the first instance) the only impurities are those in the original rock, and as a high grade rock is always used, very concentrated superphosphates are made in this way. They are known as "double superphosphates." They have an advantage in that the cost of handling and shipping per unit of phosphoric acid is much less than in the ordinary superphosphates; but they have no other advantage for the available phosphates of lime are the same in both cases.

Action of Superphosphates. The soluble or monocalcic phosphate may take up another part of lime to form the reverted of dicalcic phosphate. Soils, as a rule, contain comparatively large quantities of lime, so when the soluble phosphate is applied to the soil, it quickly reverts to the less soluble form. Soils also contain an abundance of iron and alumina which may aid in converting the soluble phosphate into an insoluble form, although it is doubtful whether this form of reversion

plays as important a part as was formerly supposed. In soils rich in lime the reversion or "fixation" of the soluble phosphate will, of course, take place more rapidly than in normal soils or in those deficient in lime, but in no case is the fixation immediate. There is always abundant opportunity for the soluble phosphate to become distributed through the soil; in fact, such distribution is necessary in order to bring the soluble phosphate in contact with the lime. For the same reasons no fear need be entertained in regard to the loss of the soluble phosphate before it can become fixed, as any attempt to wash it out of the soil would only the more quickly bring it in contact with the lime. It has been shown that even when heavy applications of soluble phosphates have been immediately followed by heavy rains, only the merest trace of phosphoric acid could be detected in the drainage water.

But if the soluble phosphate is quickly converted into an insoluble form, it may well be asked what has been gained by all the trouble and expense of converting the insoluble phosphate into soluble form. The answer is largely a matter of *distribution.* When the soluble phosphate is applied to the soil, it quickly passes into solution, and as the soil water is never at rest, the phosphate solution soaks through the soil in every direction, bathing every little particle of sand and silt and clay, and gradually being deposited among them as the necessary lime is found. These deposited or precipitated particles are extremely minute, and so expose an immense amount of surface to the action of the soil water. We have seen that the fineness of the particles of ground bones and ground phosphate rock, has much to do with their availability, but there is a far greater difference between the size of these precipitated particles and those of the finest ground bone than there is between the latter and the original bones. Again, the phosphate rock is a hard substance, and even the bones, though not so hard and much more porous, are cer-

tainly built for strength rather than for phosphatic manures; so no matter how small the particles of these materials may be, they are still compact, refractory pieces, upon which the feeble soil solutions can have but comparatively little effect. The greatest disadvantage of such materials, however, is that when applied to the soil they remain where they fall. They may be scratched about more or less by the harrow or the hoe, but even if the field could be shoveled over or run through the most improved disintegrator and mixer, the best that could be hoped for would be a comparatively inert particle here and there. The case is altogether different when the soluble phosphate is used, for the deposited particles are not only readily available when needed, but they are so thoroughly incoporated with the soil particles, that they are everywhere within easy reach of the plant roots.

The importance of the very thorough distribution so easily accomplished by the soluble phosphate has been very clearly shown in actual practice. The reverted or dicalcic phosphate was formerly used directly as a manure, being a biproduct in the manufacture of certain materials from bone, but from its action one would scarcely have suspected that it is the same material that is deposited among the soil particles when the soluble phosphate is used. It was, of course, available to such plant roots as could reach it, but it lacked the power of distributing itself quickly and uniformly. Since the introduction of soluble phosphates, it has been a matter of little interest, except to the fertilizer manufacturers, who proceed to convert it into the soluble form.

From what has been said it will be readily understood why lime and a soluble phosphate should never be appled at or near the same time, as the latter would find, within a comparatively small space, all the lime needed for its precipitation, and the advantages of thorough distribution would be lost. For the same reason soluble phosphate should never be mixed with

marl, ashes or other calcarious materials before being applied.

The amount of lime required for the fixation of soluble phosphates is almost insignificant when compared with the quantities to be found in an average soil, being less indeed than the amount of phosphoric acid applied, and even this small quantity is not lost to the soil (as when chlorides are applied) but is either taken up by plants or again set free *along with the other part of the lime that was added in the soluble phosphate*. We shall presently have to call attention to the fact that lime is the soil's principal protection against an acid condition, and it is interesting to note in this connection that the *acid* phosphates which (thanks to an honest name) have often borne the lion's share of the blame for making the soil acid (sour) are really not among the materials having such an effect.

Thomas Slag is obtained as a biproduct in the manufacture of steel by what is known as the "basic" process. This differs from the old process in that liberal quantities of lime are used for the purpose of absorbing the phosphorous with which certain iron ores are badly contaminated, and which if allowed to remain in the steel would make it so brittle that it would be worthless for many purposes. A blast of air forced through the molten iron converts the phosphorus into phosphoric acid, which unites with the lime to form the basic slag. For a long time this slag was simply regarded as one of the many useless materials which in connection with the iron industry have a tendency to accumulate. Later it was found to contain a very considerable quantity of phosphoric acid combined with lime in the proportion of one part of phosphoric acid to four parts of lime; thus:

Lime
Lime
Lime
Lime
} Phosphoric Acid

It is often known as the "tetra calcic" or "tetra basic" phosphate.

In the other phosphates of lime already considered, the solubility decreases as the lime increases, so it was hardly to be expected that this material would be any more soluble than the tricalcic phosphate, and attempts were made to convert it into a superphosphate, but it was found to be a poor material for this purpose. Meanwhile it was discovered that the untreated slag, when ground to a fine powder is certainly more readily available than the insoluble phosphate. It has attracted a great deal of attention in Germany, but it has never become very popular in this country. Some of the reports from those who have used it are very encouraging, while others are not. It has been tried at this Station, occasionally with fairly good results, but even on soils deficient in lime, the inexcusable condition for which it is often recommended, and to which its extraordinary lime content would seem to adapt it, we certainly do not regard it as a reliable substitute for a plain acid phosphate.

NITROGEN.

The atmosphere has been estimated to contain about four million billion tons of nitrogen, and this being every where present has led to the impression that nitrogen is one of the most abundant materials, but when the water and crust of the earth to a depth to which any one knows very much about it is taken into consideration, it is found that nitrogen constitutes no more than about 0.02 per cent.—even flourine and titanium being more abundant. So, while nitrogen is one of the most common materials, it is at the same time one of the scarcest. However, four million billion tons is a large quantity, and the greatest abundance for all the vegetation the surface of the earth could produce, or would be but for one strange but stubborn fact, viz: plants as a rule cannot use the free nitrogen of the air. This seems the more strange in view of the fact that 50 per cent. of the dry matter in plants may consist of carbon which is easily obtained from the 0.04 of one per cent. of carbonic acid gas in the atmosphere, and only about one-fourth of this is carbon. Yet, plants as rule cannot obtain from the 79 per cent. of nitrogen in the atmosphere the portion of one per cent. that may be needed in building up their tissues. They live in it,—in most intimate contact with it, but other sources of nitrogen failing they die of nitrogen starvation.

Plants take up by far the greater part of their nitrogen in the form of nitric acid, or some compound of nitric acid, such as nitrate of lime, nitrate of soda, nitrate of potash, etc. The essential part of nitric acid and the

part entering into the materials just mentioned, is composed of nitrogen and oxygen. So it is not until the nitrogen has been oxidized (made to unite with oxygen) that it is of use to plants. Here again we are reminded that the air contains the greatest abundance of oxygen (one-fifth of its volume) and it might seem strange that there should be any lack of a compound of nitrogen and oxygen, but there is very little tendency for these to unite. Oxygen is an active element, but free nitrogen is one of the most inert materials known, and in order to make it unite with oxygen or anything else, the expenditure of an immese amount of energy is required. When plant tissues are burned and the carbon and hydrogen unite with oxygen to form carbonic acid and water (the materials from which the tissues were so largely derived) the energy given out in the form of heat gives some idea of the amount of energy derived from the sun light when these materials were broken down and their constituents elaborated into plant tissues, but the energy of sun light is altogether too feeble to cope with the inertness of nitrogen. If but for an instant the sun's rays should be equal to this task, there would be a shower of nitric acid; and existing conditions would be a matter of the past.

Again, nitric acid is an essential constituent of all modern high explosives, such as gunpowder and the various nitro-powders, nitro-glycerine, blasting gelatine, etc. This is no accident, nor is there anything mysterious, or any energy unaccounted for in the violence with which these materials explode. The same energy, measure for measure, that is given out when these materials break down (explode) was supplied in some way when they were built up, and compounds of nitric acid are used in explosives because they make it possible to store up an immense amount of energy in a small space, and as the energy stored up in the main spring of a watch sets in motion the wheels and other mechanism, so in all probability the energy of nitric

acid and its compounds when taken up by the plant sets in motion, or in conjunction with the energy supplied by sun light, stands ready to aid at every turn in the long train of reactions incident to the elaboration of plant tissues.

When illuminating gas or natural gas is lighted the burning particles give out enough heat to ignite the adjacent particles and the burning is continuous. Now, nitrogen will burn (unite with oxygen) if heated to a sufficiently high temperature, but the burning particles do not give out the necessary heat to ignite the adjacent particles; in fact, heat is absorbed, so the nitrogen will not stay lighted unless heat is supplied from some other source. From what has been said it follows that a large amount of heat would be required, so much, indeed, that the preparation of nitric acid in this way would be very expensive.

Nitrogen may be ignited by an electrical discharge, and so it is that in thunder storms, a little nitrogen and oxygen along the path of the discharges unite and the nitric acid formed is carried to the soil by the rain. Every flash of lightning contributes to the soil's available nitrogen. The quantity, however, is necessarily very small.

The air contains a quantity of ammonia which is carried by the rain to the soil where (as we shall presently see) it is readily converted into nitric acid. This ammonia of the air is derived from decomposing animal and vegetable matter everywhere, from the burning of coal, wood, gas and other fuels containing nitrogen, and from the ocean which contains immense quantities of ammonia, a little of which finds its way to the air in connection with the evaporation of water which is constantly going on especially under a tropical sun.

The amount of ammonia in the atmosphere has been estimated to be about one pound in about 26,000,000 cubic yards of air. This is a small quantity to be sure, and it does not represent an actual gain in the available

nitrogen at the disposal of plants, but must be regarded rather as the recovery of a little of the available nitrogen that is constantly getting away from the soil. It will be interesting, however, to note the amount of available nitrogen (compounds of ammonia and nitric acid) which an acre of ground may obtain from the air in the course of a year. The quantity carried down by the rain has been determined again and again in various parts of the world, and varies from two to four pounds per acre annually, the largest quantities being obtained in the neighborhood of large cities. It has been found, however, that a much larger quantity is absorbed directly from the air by a moist soil. "Occasionally the large rain guage at Rothamsted remanis filled with snow for several weeks. When this snow melts it yields a dirty water, containing three or four times as much ammonia and nitric acid as is found in the average rain. There has clearly been a considerable gain during the long contact with the atmosphere, and the adjoining fields must have gained nitrogen to a similar extent."* Others have kept exposed to the air moist soils of known nitrogen content, and the amount of ammonia and nitric acid absorbed has always been much greater than that carried down by the rain, in some cases eight or nine times as great, but there are such wide variations in the results of the comparatively few determinations that have been made that "on the whole perhaps, the best conclusion we can come to, from the small amount of evidence at our disposal, is that the present supply of atmospheric combined nitrogen may be sufficient for a moderate yearly gain in soil nitrogen when the conditions of the soil are such that the losses of the nitrogen are reduced to a minimum—under such conditions in fact, as obtained when the land is laid down in pasture,"*—or covered by the original forests or prairies, where the soil is completely interwoven with a mass of hungry rootlets ready to

* Warington, Investigations at Rothamsted.

take up and prevent the loss of every trace of nitrogen from any source. But, as we shall presently see, when this condition of things is broken up by the plow, or when in the course of a rotation or lack of a rotation, the land lies fallow for a considerable portion of the year, the loss of nitrogen by leaching alone may be five or six times as great as all such atmospheric contributions or the amount removed by the largest crops.

We have said that plants, as a rule, cannot use the free nitrogen of the air, but fortunately this rule, like most others, has its exceptions. Leguminous plants (alfalfa, clover, peas, etc.), aided by certain low forms of life (micro-organisms) can obtain nitrogen from the air. As leguminous plants are widely distributed in nature (there being about 700 species) it is evident that they must have contributed very materially to the soil's supply of nitrogen. It is also evident that leguminous crops are useful in building up worn-out soils deficient in nitrogen; but this subject will receive special attention in Part II of this bulletin. Suffice it to say in this connection that there is a limit to the amount of nitrogen that may be added to the soil in this way, just as there is a limit to the amount that will accumulate in pastures or prairies, or that may be added to the soil by applications of farmyard manure.

The nitrogen in the soil exists very largely in the undecomposed remains of previous vegetation. The rocks, as a rule, contain very little nitrogen. Sedementary formations may still retain some of the nitrogen, derived from the vegetation of the time when these formations were being deposited in the bottom of the ocean, and the nitrogen from this source is hardly to be overlooked, as it may compare not so unfavorably with the nitrogen content of the subsoils in the same sections. At Rothamsted, samples of earth taken at a depth of five hundred feet in a calcarious clay were found to contain about the same amount of nitrogen as the clay subsoils of that section. However, it must be admitted

that "nitrogen is essentially a superficial element." The largest quantities are almost always found in the surface foot, and proceeding downward the quantity rapidly diminishes. The much smaller quantity found in the subsoil is more evenly distributed and is doubtless of much more ancient origin.

Very wide differences exist in the amount of nitrogen in different soils. Peat soils may contain three per cent, and will probably average half that amount, while marls and sandy soils may contain as little as 0.05 per cent or even 0.003 per cent. Between these extremes we have the fairly fertile arable soils which rarely contain less than 0.10 per cent of nitrogen, and the very fertile soils which as rarely contain more than 0.30 per cent. Soils as a rule contain less nitrogen than phosphoric acid or potash and this is very much more liable to loss by leaching. So the conservation of soil nitrogen is a matter of the greatest importance. Some of the unnecessary losses will receive attention presently. In this connection it will be well to note the amount of nitrogen removed by various crops, as shown by the following table:*

	Pounds.
Wheat, 20 bushels	25
Straw, 2,000 pounds	10
Barley, 40 bushels	28
Straw, 3000 pounds	12
Oats, 50 bushels	35
Straw, 3,000 pounds	15
Corn, 65 bushels	40
Stalks, 3,000 pounds	35
Potatoes, 150 bushels	40

It will be observed that the grain crops require the largest quantities of nitrogen; also that nitrogen, as a rule, has a tendency to find its way to those parts of

* Minn. Agr. Ex. Station Bull. No. 47.

the plant that are least likely to find their way back to the soil.

But here again we are reminded that even one tenth of one per cent means several thousand pounds per acre to the depth of one foot, and in view of the relatively small quantities of nitrogen required for even the largest crops, and the very marked effect that often follows the application of even a small quantity of some nitrogenous manure, the same question that had to be answered in connection with phosphoric acid and potash presents itself again, and must receive a similar answer. Only a very small part of the total nitrogen of the soil is at any time available to plants. The increase in yield following the application of an apparently small quantity of available nitrogen may indeed bear a very close relation to the increase in the nitrogen actualy at the disposal of the crop. All but a very little of the soil's supply of nitrogen is securely held in the accumulation of organic matter derived from the residues of previous crops, which being for the most part insoluble is inaccessible to plants. Like the soil's inert forms of potash and phosphoric acid, it may became available in time; the rate at which it becomes available, however, is more largely a matter of such conditions as may be fulfilled in the course of regular agricultural practices.

It should be distinctly understood that plants were not designed to feed on organic matter,—and as well, indeed, might animals try to live on a strictly mineral diet. So, before nitrogen or any other constituent of the organic matter in the soil (or from any other source) can be of any use to growing plants, it must be completely broken down to those same simple mineral substances so often referred to.

The decomposition of the organic matter in the soil is largely a matter of oxidation (combination with oxygen). The process is a slow one, and a long list of intermediate products is formed, but the final products

are much the same as if the organic matter had been burned. The carbon unites with oxygen to form carbonic acid gas, the hydrogen unites with oxygen to form water, and so on. Even the amount of heat given out is the same, though ordinarily such decompositions proceed too slowly for this to be noticeable. So the decomposition of the organic matter in the soil may be regarded as a sort of slow combustion.

The tendency for vegetable and animal substances, such as fruits, eggs, milk, etc., to decompose under certain conditions is so well known that it has come to be regarded as a perfectly normal property of such substances; so much so, indeed, that if they should refuse to decompose we would think there was something wrong with them. However, Pasteur showed that such decompositions may be postponed indefinitely by simply excluding certain low forms of life known as "micro-organisms," also known as "bacteria," or "germs." These are so very small that a thousand of them placed end to end would hardly make a line an inch long. But what they lack in size they make good in numbers. They are practically everywhere present, especially in the soil, a teaspoonful of which may contain 10 to 12 millions.

Here it should be observed that there are a great many different kinds or classes of soil bacteria, each having its own particular work to do. One kind of bacteria will carry the work as far as it can, and turn it over to another class, and so on. The result is the gradual breaking down of the extremely complex organic matter of the soil into the few simple substances (such as water, carbonic acid gas and nitric acid, etc., etc.,) from which it was originally built up. Of the long list of intermediate products formed in the course of these decompositions little is known. It may be said, however, that the nitric acid is formed from nitrous acid (a closely related substance, containing one part less oxygen), and that the nitrous acid is formed from ammonia,

each of these transformations being accomplished by a separate and distinct class of bacteria. These all work together, so there is no interruption, the change from ammonia to nitric acid taking place very quickly. This accounts for the fact that so little ammonia is ever found in the soil.

These soil bacteria, like other living things, are very susceptible to conditions, and as various soils under various methods of treatment present a great variety of conditions it is not surprising that there should be wide variations in the rate at which the nitrogen of the inert organic matter of the soil is converted into nitric acid. This process, known as "nitrification" may take place very feebly, or it may proceed on an extravagant scale. To properly control it is evidently a matter of much importance.

Like other living things these nitrifying bacteria require certain food constituents, and conspicious among these is phosphoric acid.

Nitrification can not take place in the absence of a certain amount of moisture, so it may be arrested during a drouth. Too much water, however, is objectionable, as it excludes the air which is also necessary.

There are bacteria that can get along very well without oxygen; others will die if exposed to it; the nitrifying bacteria will die if deprived of it. This is not surprising in view of the fact that the process in which they are engaged is essentially one of oxidation. In the compact lower layers of soil where the air (oxygen) is limited, nitrification proceeds but feebly, while if the air is completely excluded nitrates cease to be produced; indeed, a reverse process sets in, and existing nitrates are robbed of their oxygen, the nitrogen being set free.

Another important condition is that of a suitable temperature. At a temperature of about 100 degrees F., or near that ordinarily designated as "blood heat," nitrification proceeds most rapidly. As the temperature rises above this point the action decreases, being

very feeble at 120 degrees while at about 130 degrees it stops. As the temperature falls below 100 degrees the action decreases; though not so rapidly, being very feeble at 40 degrees. From the above it follows that while nitrification will, of course, be more active in summer, it will be going on pretty freely during an average winter.

In the course of the decomposition of the organic matter in the soil a long list of complex materials are formed, and some of these materials are acids. Of course the nitric acid, into which the nitrogen is finally converted belongs to the same class. Strange to say the organisms so instrumental in the formation of these acids cannot work in an acid medium; in other words the products of their own work may accumulate until they are compelled to suspend operations. This undesirable condition, however, can only obtain when the soil is lacking in lime, for if the lime is present in normal quantities the acids, as they are formed, will unite with it to form neutral substances, the acid properties being destroyed, and nitrification proceeding without interruption.

In this connection it is to be observed that not all of the many kinds of germs to be found in the soil are to be regarded as favorable to agricultural interests. There are yet other kinds of soil bacteria which, in the absence of the conditions above described, may gain the ascendency, and not only give rise to unfavorable decompositions, but may even undo the valuable work of the nitrifying germs, reducing the nitrates already formed to free nitrogen gas. As would naturally be supposed the conditions most agreeable to these unfavorable germs are the reverse of those just mentioned. Prominent among them is the want of sufficient oxygen. By simply excluding the air, the destruction of the nitrates can be made to take place in a soil that is otherwise in good condition. The exclusion of the air can be accomplished by simply saturating the soil with

water, and so it is that "water-logged" soils are sure to suffer.

Another condition promoting the destruction of the nitrates, and of equal or even greater importance, is the presence of an excess of organic matter, for the destruction of nitrates will take place even in the presence of air, if only there be a sufficient amount of putrifying organic matter. Such conditions are responsible for some of the losses of nitrogen in manure piles. Such losses are not likely to occur in arable fields and yet there is doubtless a limit to the amount of organic matter that a soil can handle economically. Soils naturally rich in organic matter, or that have been made so by heavy applications of farmyard manure, are certainly the most liable to such losses, and especially when a a series of heavy rains keep them saturated for a time with water.

Losses of Available Nitrogen by Leaching—The soluble forms of potash and phosphoric acid are quickly and securely fixed by the soil, so there is little danger of loss by leaching; but such is not the case with nitrates, the soil having no power whatever to convert them into soluble forms. Unless taken up by the plant they are simply carried about by the soil water. A heavy rain will carry them to the lower layers of the soil. Evaporation from the surface causing an upward current in the soil water, may carry them back to the surface soil, but a part is sure to be carried away in the drainage water. Once formed, they must be used or lost.

Other things being equal, nitrification proceeds most rapidly when the ground is bare. This, of course, accounts in a measure, at least, for the increased yields that follow a bare fallow, but it should be observed that while the amount of nitrates at the disposal of the succeeding crops may be greatly increased in this way, the loss by leaching may be several times as great.

Other things being equal, nitrification will proceed most rapidly in soils that are rich in organic matter,

such as rich prairie lands, or new lands just broken. In such cases, to be sure, there is not the same reason for leaving the land in bare fallow, but certain agricultural practices amount to practically the same thing. From what was said in regard to the temperature most favorable to nitrification, it follows that by far the greatest part of the nitrates must be formed during the summer and early fall. Certain crops, wheat for example, must have nitrogen or suffer for want of it, very early in the summer, leaving the soil bare during the long period when nitrification is most active. In order to avoid the loss of nitrates by leaching, the soil must be kept covered by a crop of some kind. Permanent pasture is the ideal condition, the loss of nitrates being reduced to the minimum. Of course all soils cannot be kept in permanent pastures, but by following a proper rotation of crops such losses may be greatly diminished.

So much for the decomposition of nitrogenous organic matter in the soil. We have given the subject more space than would have been necessary in a bulletin of this kind, but for the fact that the great majority of nitrogenous manures consist of animal or vegetable matter which can be of no use as foods for plants until completely decomposed. Most nitrogenous manures decompose much more quickly than the organic matter of the soil, but the fact should not be overlooked that such decompositions are subject to the same conditions and the same liability to loss by leaching, etc.

Catch Crops and Green Manuring will receive special attention in Part II of this bulletin. It is evident, however, that they must have much in common with the crop residues and other organic matter in the soil, and arguments in their behalf have already been presented incidentially. It is evident that they may be used to prevent the loss of nitrates, also that by properly selecting the catch crop nitrogen may even be added to the soil. Then, again, crops vary widely in their ability to obtain certain constituents from the soil, and

it is possible to select the crop that is to be used as a green manure with reference to any lack of ability on the part of the succeeding crop to obtain such constituents from the soil. The organic matter which has so many valuable functions to perform in the soil, and which is added in such abundance where a green crop is plowed under, is not to be overlooked. Indeed, organic matter may be supplied more uniformly and economically by plowing under a vigorous green crop than by applying stable manure, or by any other known methods. These and many other points will promptly suggest themselves to those who may have been disposed to look into the possibilities of catch crops and green manuring. It may, however, be well to observe, first, that it is necessary that the soil be capable of producing the catch crop, and second, that it is one thing to catch when you can and quite another thing to let go when you please. For while the delicate, succulent green crop plowed under may under favorable conditions be depended upon to decompose quickly, turning over to the succeeding crop the plant food culled from the soil and air, such decompositions are limited and controlled by the same conditions so often referred to. Conspicuous among these is the presence of a sufficient quantity of some basic material, such as lime. Indeed, for reasons similar to those that should be suggested by the old saying that "lime without manure" exhausts the soil, etc., it is extremely important that *a soil to which is added such large quantities of organic matter be not deficient in lime.*

Certain vegetable products are so rich in nitrogen that they are often applied to the soil as nitrogenous manures. They also decompose quickly when applied to the soil, so that previous decomposition is unnecessary. Among these may be mentioned cotton seed meal, linseed meal and castor pomace.

Cotton Seed Meal may contain nearly seven per cent of nitrogen. It is used in large quantities, principally

in the southern states, where it is to be had in abundance. It is also a very excellent food for cattle and as its value for this purpose comes to be appreciated, its use as a manure must decrease.

Linseed meal contains on an average about 5.5 per cent of nitrogen. Its extensive use as a cattle food makes it too expensive, as a rule, for use as a manure.

Castor pomace is the product left after removing the oil from the castor bean. It will average six per cent of nitrogen, and decays rapidly when applied to the soil. Unlike cotton seed meal, it can not be used as a cattle food, so it may be had at prices consistent with its use as a fertilizer.

Farmyard manure probably has more in common with the organic matter of the soil than any of the nitrogenous manures we shall have to mention. It consists of vegetable matter that has undergone more or less decomposition in passing through some animal, and which together with more or less litter has been subjected to further decomposition in the manure pile. For these reasons more or less of the organic matter of the manure will be in a more advanced stage of decomposition than much of the organic matter of the soil. A large part of it, however, can be no more readily available than that already in the soil. In this connection we are reminded that the liquid excrement contains much nitrogenous matter, which if it ever reached the soil would be quickly available, but farmers, as a rule, pay so little attention to this that it can hardly be said to constitute a very considerable part of the product known as farmyard manure. The composition of the material which finds its way to the manure pile, and from there to the fields, will depend upon the nature of the materials used for bedding, as well as those used for feeding stuffs. It will also depend upon the kind, age and condition of the animal, but the conditions to which it is subjected in the manure pile are the matters

of the most importance. Here decomposition may take place very rapidly, and it is upon these decompositions that the superiority of the manure as a plant food depends.

From what has been said in regard to the decomposition of organic matter, it follows that nitrates will hardly be formed. Most of the germs that thrive in manure piles must be able to get along without air, and all must be able to work in the presence of large quantities of organic matter. The decompositions which can take place, however, result in the elimination of a large part of the useless carbonaceous matter (as carbonic acid gas and water) thus reducing the bulk and concentrating the more valuable constituents. Part of the nitrogen is converted into ammonia, and as the conditions will not admit of the conversion of ammonia into nitric acid, it simply unites with the carbonic acid, which is being formed in such abundance, to form carbonate of ammonia. This is not only a very soluble material, and consequently liable to lose by leaching, but it is also a very volatile material and particularly liable to escape to the air. The strong odor of ammonia which usually inspires confidence in a pile of manure, is really but the evidence of what is being lost. This volatilization of ammonia, may, of course, be prevented by adding to the manure some material that will unite with the ammonia to form a non-volatile compound. There is no lack of such materials, but the great bulk and small value of the manure makes it necessary to use something very cheap. Gypsum (sulphate of lime) is often used, and it has some value, of course, as an indirect manure. Acid phosphates might be used for this purpose since gypsum constitutes about one-half of their weight and such a practice is to be commended as it would greatly increase the phosphoric acid content of the manure. Some of the crude Strassfurt salts, which are rich in sulphate of magnesia, may be used and these have the advantnge of raising the

potash content of the manure. In the course of the decompositions which take place in the manure pile (as in those taking place in the soil) other acids than carbonic acid are also formed, and a part of the ammonia will unite with some of these to form substances that may be found in the dark liquor that oozes from manure piles exposed to leaching.

It must not be understood, however, that all the nitrogen is converted into ammonia. There could certainly be very little reason for believing that the sticks and straws are very different from other sticks and straws, and much of those portions which are in a more advanced stage of decomposition may still be a long way from the ammonia stage. It is to the ammonia and the constituents in the more advanced stages of decomposition that the immediate effects of farmyard manure must be due. The rest can only contribute to the "lasting effects" for which so much is always claimed; indeed, for lasting properties much of it will compare not unfavorably with the great mass of organic matter already in the soil, and its decomposition in the soil must be attended with the same uncertainties.

The actual amount of nitrogen and other constituents of plant food to be found in farmyard manure will vary within wide limits, though the quantities are always very small. The quantities in the litter which constitutes so much of the bulk are very small; so are the quantities in the food stuffs, and a part of this is used by the animal in building up its tissues. To be sure a corresponding part, representing worn out tissues is excreted, but the nitrogen finds its way to the liquid products, so much of which is usually lost. As a result of the decompositions in the manure pile, the bulk may be reduced fifteen to fifty per cent., but this may be accompanied by a corresponding loss of nitrogen from volatilization, leaching etc.

It would be possible, of course, to select the litter and feeding stuffs with reference to their value as a manure,

the liquid products might all be used; the solids might be protected from loss by volatilization and leaching, and the fermentation might be made to take place as it should, etc. but the product would not be what is usually known as farmyard manure. Whether the difference in the two products is worth the difference in the cost of production is the question, and this the majority of farmers seem to have answered at least to their own satisfaction, and most emphatically in the negative. However, it would seem that a little systematic effort in the direction of decreasing these losses, which could be made at a trifling expense, and really in the the interest of cleanliness and tidiness and would prove a good investment.

Farmyard manure will, as a rule, contain something less than one-half of one percent of nitrogen, about the same amount of potash and about half as much phosphoric acid. It should be needless to add that only a part of these small quantities can be regarded as very readily available. It would take thirty to forty tons of farmyard manure to furnish as much total nitrogen as one ton of nitrate of soda, and it would take a much larger quantity to furnish as much nitrogen in available form.

Guano was the first commercial fertilizer to be used extensively. Bones had been used in a small way for a long time, but the marvelous results following the application of this wonderful brown powder enabled it to easily eclipse all other manures, and so great was the demand for it that one enormous deposit after another was quickly exausted, until at the present time guano is practically a manure of the past. Yet, its influence on agriculture can hardly be over-estimated. "It introduced the modern system of intensive cultivation, and prepared the way for the now almost universal practice of artificial manuring." *

Guano, as every one knows, is derived almost exclu-

*Aikman.

sively from the excrement of sea birds, and the remains of birds themselves.

Its composition varies with the conditions to which it was exposed. In the warm, dry rainless regions it suffered little change, and under such conditions the richest deposits were formed. Not all of the deposits, however, were so fortunately located, and as the moisture of the various localities increases, the soluble constituents decrease until in the Baker's Island deposits, for example, not only the nitrogen and potash but even the soluble phosphates have been leached away, leaving little of value but the insoluble phosphate of lime.

The Peruvian Guano was the richest in nitrogen, often containing almost as much of this constituent as nitrate of soda. The nitrogen which was readily available was present largely as salts of ammonia and uric acid.

Farmyard manure like guano also consists essentially of animal excrements, and in view of the wide difference in the value of the two products it may be worth while to consider the production of guano from the standpoint of the factors already mentioned as determining the composition and value of farmyard manure. In the case of guano the food stuffs consisted of fish, which themselves are so rich in nitrogen that they constitute an important source of nitrogen in commercial manures. Little or no litter was used except the carcases of birds and other animals, which are also rich in nitrogen. The liquid and solid products were already mixed while a rapid fermentation resulting in the loss of ammonium carbonate was prevented by lack of moisture, which also prevented loss by leaching.

Fish Guano. Fish are very rich in nitrogen, and the "dried ground fish," "fish scrap" and "fish guano" are obtained from the offal of the fish packing or canning houses and from the pomace that is left after extracting fish oil. The product derived from the packing houses varies widely in its content of nitrogen and

other constituents but the pomace is fairly uniform in composition, rich in nitrogen, and a most excellent nitrogenous manure. It will average 7 to 8 per cent of nitrogen, and 6 to 8 per cent of phosphoric acid.

When applied to the soil, if the conditions are favorable, fish scrap decomposes rapidly, that is, rapidly, as compared with the rate at which such decompositions usually proceed. It is not to be suppsed for a moment that the value of the nitrogen in fish scrap is to be compared with that of nitrate of soda, for example, which is immediately available. Placing the availability of nitrate of soda at 100, that of fish scrap is usually put at 60. As a rule a part of any organic product is more quickly available than the rest of the mass, and so in the case of fish scrap, a part is quickly available, other parts of it will require more time, and there is doubtless a part that will decompose so slowly that it would be hard to tell what crop was benefited by it. When considering the availability of animal and vegetable products the advisability of feeding the soil as well as the crop is always before the house. In the case of fish scrap an unusually large part of nitrogen may be expected to become available during the growing period of a single crop. The fact that the nitrogen is not immediately available, but may become available as the season advances, may even be an advantage in that the crop may be fed more uniformily —at least after the decompositions are well under way, and provided, of course, that the season and other conditions are favorable. So many crops require so much of their nitrogen during a comparatively short period, early in the course of their development, that it is hardly safe to depend upon the season and the conditions referred to, and so it is often advisable to use along with the fish scrap (and other organic forms of nitrogen) more or less of some immediately available form of nitrogen. That manufacturers of commercial fertilizers are coming to realize the importance of some

immediately available form of nitrogen (independent of the conditions controlling the decomposition of organic materials in the soil) would seem to be evident from the rapidly increasing number of brands containing nitrate of soda.

Fish scrap is an excellent source of nitrogen for many crops, and being a biproduct it can usually be had at a reasonable price. It is used extensively in the manufacture of commercial fertilizers, and as farmers come to appreciate its value it will doubtless become a very important source of that expensive constituent of plant food. The following paragraph from Storer's valuable work is very much to the point:

"Thousands of tons of worthless fish are captured every year at the fishing stations, that is to say, fish like whiting, skates, and sculpins, dog-fish and other sharks, which have no merchantable value to say nothing of good fish that become tainted in hot weather, or of the waste portions—heads, fins, entrails and bones—of cod, haddock, halibut and the like. It is neither a difficult or costly matter to dry and grind these waste fish whenever the farmers care enough for the product to make it worth any one's while to prepare it.

"More than this, very large quantities of the worthless fish, might readily be caught on purpose, if there were any sufficient demand for fish scrap to make them worth the catching. Those now caught are caught against the fisherman's wishes—in spite of him, in fact. There is a never-failing supply of fish in the sea, where there is almost an infinite amount of room, and where man has small power to annihilate, or even to thin out the migratory fishes.

"There can be no doubt that in the future, when the increase in population shall enforce a more intelligent agriculture, the drying of fish scrap will become a highly important branch of industry. It bears even now very curiously upon the question of utilizing the sewage of cities. The reproach has often been made, that the

modern system of removing filth from cities by means of water closets and sewers flowing to the ocean is wasteful, unphilosophical and wrong. But it appears from what has just been said, that such censure is hasty and ill-considered. So long as a clean, innocuous and concentrated manure can be got from the sea, in the shape of fish scrap, at less cost of money, labor, health and life even than would have to be expended in transporting the city filth to the farm, or in converting it into transportable form, it would be mere folly for the farmers to waste their energies upon sewage."

Meat Meal Guano is one of a series of products obtained from the slaughtering establishments. Various portions of the animal bodies are treated with steam for the purpose of extracting the fat and other constituents. The extracted material decomposes quickly, and as it may contain thirteen or fourteen per cent of nitrogen, it is a valuable nitrogenous manure.

Tankage is a highly nitrogenous product, but it is so variable in its composition that its value is always based upon its analysis. It is made up of the otherwise unsalable slaughterhouse refuse, such as bone, hide, hoof, hair, etc. Several grades of this "crushed tankage" are to be found on the market, ranging from four to nine per cent of nitrogen, and from three to twelve per cent of phosphoric acid. Even these wide limits will not include all the tankage to be found on the market. There are products containing even smaller quantities of nitrogen, and larger quantities of phosphoric acid; such products, however, consist largely of bone. There is also a material known as

Concentrated Tankage prepared by evaporating the fluids obtained in extraction processes. This is in splendid mechanical condition, decomposes quickly, and while it contains little phosphoric acid, it may contain ten to twelve per cent of nitrogen, and so must be classed as a valuable nitrogenous manure. Immense

quantities are used in the manufacture of commerical fertilizers.

Other waste products, such as hair, hoof meal, horn meal and leather meal, are very rich in nitrogen, often containing as much as fifteen per cent, but they decompose so slowly that they are of little value as a manure. They can be recommended only to those who believe in feed ing the soil, or to those who attach so much importance to the "lasting effects," in regard to which we always hear so much, for these materials have lasting properties to give away; indeed, they are likely to last so long when applied to the soil that no one will ever know just when they did became available. These materials are sometimes used to adulterate other more readily available nitrogenous materials like dried blood and tankage, thus greatly increasing the content of the total nitrogen without adding anything to the nitrogen at the disposal of the crop.

Dried Blood is by far the finest of the numerous nitrogenous products furnished by the slaughter houses. It is very rich in nitrogen often containing almost as much nitrogen as nitrate of soda, and as it contains no tough or refractory particles, and has been so finely divided that it could exist as a fluid, it is (providing the drying has been carefully done) in most excellent mechanical condition and decomposes very quickly when applied to the soil. The market recognizes two grades—the red and the black. The red blood is obtained by carefully drying fresh blood at a temperature not high enough to char it. It is of fairly uniform composition, containing thirteen to fourteen per cent of nitrogen and very little phosphoric acid. It is the richest organic nitrogenous manure, but unfortunately (from an agricultural standpoint) it is valuable for other purposes. The black blood is not so pure, so carefully dried, so quickly available, so rich in nitrogen or so poor in phosphoric acid, and as it is not so useful

for other purposes it is used extensively in the manufacture of commercial fertilizers.

The nitrogenous materials considered thus far, including the mass of organic matter in the soil, are derived from vegetable or animal tissues. Before they can serve as plant food they must all decompose. The decomposition is largely a matter of conditions which may or may not exist. Granting the conditions favorable the value of such materials will depend not alone or really so much upon the amount of nitrogen contained in them, as upon the *rate* at which they will decompose when applied to the soil. In our brief and imperfect discussion of the decomposition of organic nitrogenous matters in the soil, only two or three of the last and simplest decomposition products were mentioned, and the first of these was ammonia, into which form it is quite possible that by far the greater part (if indeed not all) of the nitrogen of the organic materials is converted before becoming available to plants. That the nitrogen in the ammonia stage is far more readily available than that in the original organic matter goes without saying, for it has already been completely freed from the mass of carbonaceous matter with which it was entangled, and lacks but few transformations of being in the form in which plants can use it. Under favorable conditions these few remaining transformations take place very quickly; so quickly indeed that although it is usually claimed, and is doubtless true, that plants can take up a part of their nitrogen in the form of ammonia, it is difficult to determine how much of the ammonia supplied to plants is taken up as such before being converted into nitric acid. Ammonia is to be found on the market and although it is an expensive material it may be had at prices admitting of its use as a fertilizer, for which purpose it is usually obtained in the form of the

Sulphate of Ammonia. Pure ammonia is a gas. It is very soluble in water, and it is the water solution of

ammonia that is so familiar to every one as "ammonia water." Ammonia is a very simple substance, being composed entirely of hydrogen and nitrogen. Both of these substances in the free or uncombined condition are gasses. When they unite to form ammonia, one part by volume of nitrogen unites with three parts of hydrogen. This, however, does not give the proportion by weight, for nitrogen is fourteen times as heavy as hydrogen. So, ammonia consists of fourteen parts, by weight, of nitrogen and three parts, by weight, of hydrogen; or, 1.00 per cent of ammonia is equal to about 0.82 per cent of nitrogen.

When vegetable and animal substances are subjected to dry distillation a part of the nitrogen unites with a part of the hydrogen to form ammonia, and so it is that in the manufacture of illuminating gas from coal (which may contain from 0.50 to 1.50 per cent of nitrogen) more or less ammonia is formed. Only a small portion of the nitrogen of the coal is converted into ammonia, the rest being lost, and yet illuminating gas is manufactured in such enormous quantities that most of the ammonia of commerce is obtained that way.

Free (or gaseous ammonia) would be a very bulky product, so largely for the purpose of concentrating it, it is treated with sulphuric acid, with which it readily unites to form sulphate of ammonia, a beautiful white crystaline solid, containing about one-fourth of its weight of ammonia, or 21.2 per cent of nitrogen. The commercial product is usually more or less colored with certain impurities, which for agricultural purposes it would be false economy to remove. Such impurities, together with more or less moisture may reduce the nitrogen content to twenty per cent, but even at this figure it is the most concentrated nitrogenous material obtainable at the present time for agricultural purposes. It is used extensively in the manufacture of commercial fertilizers.

We have already had occasion to refer to bone black

as a product of the dry distillation of bones, and need only to add in this connection that a part of the nitrogen is sometimes recovered as ammonium sulphate.

In the manufacture of illuminating gas and bone black the coal and the bones are heated in receptacles precluding the access of air, thus making it possible to collect the volatile substances driven off by the heat. In the manufacture of coke, which proceeds on such a gigantic scale in this state, enormous quantities of coal are subjected to a sort of dry distillation, but the usual form of coke oven makes no provision for saving the ammonia or other valuable gaseous products. There is a form of oven, however, that makes it possible to recover some of the ammonia and other volatile products that otherwise would be lost. The "biproduct ovens" are slowly but steadily coming into use; their influence is already preceptible on the ammonia market, and we may at least look forward to the day when sulphate of ammonia will be within easy reach of the agriculturist.

In connection with lime it will be stated that the soil has the power of fixing ammonia, but this should not encourage a careless use of ammonia compounds, as the change from ammonia to nitric acid may take place quickly; so quickly that the avaliability of sulphate of ammonia ranks next to that of nitrate of soda. It is necessary, however, that the few remaining changes, from ammonia to nitric acid, take place, and the conditions so often referred to must obtain. Conspicuous among these conditions is the presence of some basic material, such as lime. In fact, it has been shown that sulphate of ammonia on acid soils (soils deficient in lime) may even be worse than no fertilizer at all. The reason is not hard to find. Sulphate of ammonia is a neutral substance, but as a result of the nitrification process, the ammonia is converted into nitric acid, so for every quantity of neutral sulphate of ammonia added to the soil, two quantities of acid (nitric acid and sulphuri

acid) are formed, and a corresponding amount of lime will be required to nutralize them.

The amount of lime required to neutralize the acids formed from the quantity of sulphate of ammonia usually applied to an acre of ground is really insignificient when compared to the amount of lime to be found in an acre of normal soil. It is only when a soil is deficient in lime, that the little lime required for an application of sulphate of ammonia becomes a matter of any importance; and after all there is no excuse for allowing a soil to become deficient in lime.

Nitrate of Soda has been mentioned so often that little need be added to what has already been said. Nitric acid, or some compound of nitric acid, such as nitrate of lime, nitrate of potash, nitrate of soda, etc., is the form in which plants, as a rule, take up their nitrogen, and the final form into which the nitrogen of the organic nitrogenous materials in the soil as well as those added to the soil as fertilizers, must be converted before it can be of any use to plants.

The nitrogen in nitrate of soda being already in the form required by plants, possesses a decided advantage over the various forms of organic nitrogen mentioned in that its action does not depend upon the decompositions which such materials must undergo, or the conditions upon which such decompositions depend. The nitrogen in nitrate of soda is immediately available.

Nitrate of soda is quickly soluble in water, and as the soil has no power to convert it into a less soluble material, it is readily distributed among the soil particles to every point where nitrogen may be needed. This, however, suggests the only danger in applying nitrate of soda—the danger of loss by leaching. Once applied to the soil it must be used or lost, but being immediately available it may be applied just as it is needed, and this suggests the rational method of using nitrate of soda,—in small quatities and as needed by the crop,—say in two or three applications according to the length

of the growing period. Such a method, of course, entails some additional labor and expense, but with no other nitrogenous material obtainable for manurial purposes at the present time, is it possible for the farmer to have the feeding of the crop so nearly under control. The nitrogen in farmyard manure and other organic nitrogenous materials, may become available as needed by the plant or it may not. It may, for example, become available most rapidly after the crop has ceased to need it, thus prolonging the period of growth and encouraging an abnormal development of stems and leaves, which, while they might be very desirable in some crops, would not be so desirable in others. By the use of nitrate of soda and other quickly available nitrogenous materials such difficulties (and many others) may be avoided.

Nitrate of soda is to be had in abundance and at prices that place it within easy reach of the farmer. All things considered it is one of the cheapest nitrogenous materials on the market. Immense deposits are found in various rainless districts in South America. As to just how these deposits were formed, no one is quite sure. Some think they are derived from guano, which was formerly obtained in such abundance from similar localities. One of the difficulties with this theory is the absence of phosphate of lime. According to another theory the nitrate of soda is derived from sea weeds. This theory is supported by the presence of iodine, large quantities of which are extracted in the course of the purification. The purified product as found on the market usually contains about 95 per cent of nitrate of soda or about 15.5 of nitrogen.

LIME.

Lime is not one of the materials likely to be deficient in the soil, at least in the quantities necessary to meet the immediate demands of plants for this constituent of plant food. So lime is not to be regarded as a "direct" or "nutritive" fertilizer, but lime has so many other functions to perform in the soil (many of them almost, if not quite, as important as that of supplying plant food,) that a few words in regard to lime as an "indirect" manure may not be out of place.

Lime is one of the oldest and one of the most popular of all manures. It is mentioned, and its wonderful action commented on, in the works of several ancient writers, more especially Pliny. Centuries before potash, phosphoric acid or nitrogen had been heard of, the value of lime as a manure was well known, and definite rules for its use had been established. Its earliest champion in this country was Edmund Ruffin, who devoted the best years of his life to demonstrating the value of lime, in the form of marl, on certain upland soils of Virginia. The results of his work were published from time to time in the American Farmer (1818), and finally in a comprehensive report entitled "Calcareous Manures," which passed through several editions.

During the past few years, Wheeler, of the Rhode Island Experment Station, has given the subject of "Lime and Liming" a good deal of attention, and has shown that in the eastern part of this country lime is badly needed on many soils that had been thought to contain it in sufficient quantities for all purposes.

Notwithstanding the fact that lime has been used so

long as a manure, there is probably no other manurial substance in regard to which there are so wide differences of opinion. "In some sections of the country the farmers use it to such an extent that at certain seasons of the year the ground is white with it, while in other sections it is used very sparingly, if used at all, and land owners often refuse to lease their farms, except on condition that no lime be used." *

There are wide differences of opinion, also, as to the kind of soil that is likely to be most in need of lime. In some countries it is claimed that heavy soils, in others that light, sandy soils, are most improved by liming. It is evident that there are a few points, at least, in regard to the action of lime that are not thoroughly understood. One reason for this is doubtless to be found in the fact that lime acts in so many different ways, and the changes which it brings about in the soil, although always complicated, vary widely in different soils.

Amount of Lime in the Soil. Lime is one of the most abundant constituents of the earth's crust, and probably forms not less than one-sixteenth of the rock mass of the earth, at least to the dept to which any one knows very much about it. It often forms whole mountain ranges, so that vast tracts of country are derived almost exclusively from limestone. Nearly all the common rocks and minerals contain it, and in the course of their decomposition yield it up to the soil.

In view of the great abundance of this material in the rocks, from which the soils are derived, it may be in order to account for the comparatively small amount, 0.2 per cent to 0.6 per cent, that is to be found in the average soil.

Lime is practically insoluble in pure water, but this is not the case with water containing carbonic acid. As has already been pointed out, the soil water always con-

* Agriculture, Storer.

tains carbonic acid, which is capable of dissolving out appreciable quantities of the hardest and least soluble of soil constituents, and lime is one of the constituents most susceptible to the action of the soil water, as is evident from the fact that the water in the springs and wells of limestone countries, usually contains lime in sufficient quantities to be easily detected by the taste. The quantity of lime removed by a given quantity of water may be small, but the process is continuous and it has been going on for untold ages, even during the formation of the rocks, from which many of the present soils are derived. So it is that while lime is one of the most abundant constituents of the rocks from which the soils are derived, and while lime is usually to be found in the soil in quantities sufficient for all purposes, it is, nevertheless, one of the most variable constituents of the soil and may be present in quantities as large as 15 per cent to 20 per cent, or as small as a few hundredths of one per cent.

Different Forms of Lime. Lime occurs principally as the carbonate of lime, in the forms of ordinary limestone, marble, etc. It occurs also in several other forms, among which may be mentioned sulphate of lime or gypsum, which will receive attention presently, and the phosphate of lime already considered.

Ordinary limestones never consist entirely of carbonate of lime, as they always contain more or less other earthly matter, chiefly silica, oxide of iron and alumnia, with traces of phosphate of lime, potash, soda and organic matter. In limestones of good quality, these impurities should not exceed 5 per cent, and they are often present in much smaller quantities. In the poorer limestones, the impurities may amount to 15 per cent or 20 per cent or more. These impurities, it will be observed, are among the materials to be found in all good soils, so they can not be regarded as injurious. They are simply objectionable as representing so much useless matter to

be handled, and because they may interfere with the proper burning and slacking of the lime.

Another constituent of limestone which may be regarded as an impurity is carbonate of magnesia, which closely resembles the carbonate of lime in many respects. It may be present in quantities varying from a fraction of one per cent, to quantities so large that it assumes an importance equal to that of the lime, when the material is known as magnesian limestone, or dolomite. These dolomitic limestones are very abundant in nature, often forming whole mountain ranges.

As every one knows, limestone may be readily converted into "burnt lime," "quick lime," or "caustic lime," as it is often called, and that this, in turn by treating with water, may be converted into "slacked lime," which may unite with carbonic acid gas to form the carbonate of lime. It may be well to review these changes briefly, as they will help explain the action of lime when applied to the soil.

When carbonate of lime, in the form of limestone, marble, oyster shells, etc., is heated to a sufficiently high temperature in some arrangement admitting a current of air, a large quantity of carbonic gas is driven off, leaving the burnt lime or caustic lime. This is much lighter than the original carbonate, although occupying the same space. Pure carbonate of lime, completely burnt, loses 44 per cent of its original weight, the loss representing the weight of the carbonic acid gas expelled. So the carbonate of lime may be said to be composed 56 parts of caustic lime and 44 parts of carbonic acid gas.

Caustic lime, as the name implies, is a strongly alkaline or basic material, which readily unites with acids to form substances possessing neither acid or caustic properties. United with phosphoric acid, it yields the phosphates of lime, and we have just seen that it combines with carbonic acid to form the carbonate of lime. Indeed, if caustic lime is allowed to remain exposed to

the air, it will take up carbonic acid gas from the air, and pass back to the carbonate. The best known property of quick lime is doubtless its strong affinity for water, which it absorbs in large quantities, and with the evolution of a great deal of heat, while the lime swells to several times its original valume, and crumbles to a fine powder. It will even absorb moisture from the air. The slacked lime, which is formed when caustic lime unites with water, is somewhat soluble in water, possesses caustic properties, and neutralizes acids with the formation of substances similar in every respect to those mentioned in connection with caustic lime. When caustic lime is applied to the soil it soon finds the necessary moisture to convert it into slacked lime, while the carbonic acid in the soil water converts this into the carbonate of lime. But this the form in which lime exists in limestones, and what has been gained by the burning and slacking? By burning and slacking the lime is reduced to an extemely fine state of subdivision, finer, by far, than could ever be reached by grinding the original limestone. The slacked lime is somewhat soluble, and so may be transported by the soil water and deposited over an immense surface of soil particiles. The same points in regard to the fineness of subdivision and ease of distribution, so often urged in connection with the availability of phosphates, apply equally well here. Again, it requires time for either quick lime, or slacked lime to take up all the carbonic acid it would need to become converted into the carbonate, meanwhile the soil is getting the benefit of the caustic action of the lime, which will be considered later. The finely divided carbonate of lime deposited among the soil particiles is easily dissolved by the soil water, and so may be taken up by plants or perform the numerous other functions upon which the value of lime depends.

Evidently the value of a quick lime will depend largly upon the ease with which it will slack or crumble to powder, and this will depend, to some extent at least, upon the manner in which it is burned.

The Burning of Lime. The lime kiln may simply consist of a sort of log heap, with the lime piled on top and inside, the whole being so arranged as to allow free access of air, and burn freely. This simple arrangement, which is still doing good service, has probably been in active use for more than two thousand years. Sometimes the pile of limestones and logs is covered over with a layer of sod, and from this simple kiln has been evolved the immense structures of solid masonery, or of steel boiler plate lined with fire brick, in which lime is now burned on a large scale. Some of these kilns are so arranged that the process is contintinuous, the fuel and limestone being fed in at the top, while the burned ime is drawn out at the bottom of the kiln. In all these arrangements the ashes of the fuel, of course, is mixed with the lime. There are other arrangements, in which only the heated gases from the burning fuel enter the kiln.

In burning lime a bright red heat is usually employed. Too high a temperature is to be avoided, as "over-burnt" or "dead burnt" lime is likely to be the result.

The size and composition of the lumps will effect the facility with which limestone will give up its carbonic acid gas on burning; but next in importance (if indeed, not of equal importance) to the temperature employed, is a sufficient volume of air, or other gases, passing through the heated mass of limestones to carry away the carbonic acid gas as fast as given off, for it is a notable fact that in an atmosphere of carbonic acid gas, the carbonate of lime may be heated to a temperature far beyond that ordinarily used to decompose it, and remain practically unaffected. A current of steam is sometimes used to help carry off the carbonic acid gas, while wetting the limestone, and even wetting the fuel has been found to be advantgeous.

To burn limestones of different composition requires some experience. They can not all be treated in just the same way. Carbonate of magnesia gives up its

carbonic acid gas more readily than the carbonate of lime, and so dolomitic limestones will require less fuel and stand a better chance of being over-burnt. If the limestone contains much impurities, the temperature used will require more attention, as the silica and alumina may be fused into a sort of slag or glass, which will greatly interfere with the slacking. Limestones of very different composition should never be burned in the same kiln at the same time. Other things being equal, the purer the limestone, the more likely it is to be properly burned by parties of limited experience.

Varieties of Burnt or Quick Lime. Fresh burnt lime retains practically the same volume and shape of the original limestone, which fact makes it possible to tell to what extent lime has become air slacked. The common test for the quality of quick lime is the readiness with which it slacks. Good, fresh, burnt lime, slacks readily, evolving a great deal of heat, and yields what is known as "fat" lime. If the lime contains much impurities, or if it has not been properly burned, or if it has been allowed to become partially air slacked, it will slack indifferently or with difficulty. Lime from dolomitic or magnesian limestone slacks more slowly and yields a "thin" or poor lime. Lime containing certain impurities in considerable quantities will harden under water and is known as "hydraulic" lime. The best quick lime is obtained from limestone. When freshly burned it weighs from 90 to 95 pounds to the bushel, and will slack to about three bushels.

Oyster shell lime is generally 85 per cent to 95 per cent pure, weighs about sixty pounds per bushel, and will slack to something over two bushels.

"Gas" Lime. Quick lime is used in large quantities to remove certain impurities from illuminating gas. After it has become exhausted for this purpose, it is often used for agricultural purposes. It varies considerably in composition, but consists essentially of slacked lime, carbonate of lime and sulphate of lime together with

more or less sulphite of lime and sulphide of lime. The last two compounds are poisonous to young plants, but on exposure to the air they are converted into sulphate of lime, which, of course, is not injurious. For this reason gas lime should always be applied, or exposed to the air, some time before the crop is planted.

Action of Lime. Experience in the greatest abundance has shown that lime often improves the mechanical condition of the soil, making light sandy soils more compact, and heavy clay soils lighter and easier to work; that it favors clover and the grasses and helps to eradicate sorrel and other weeds; that it sometimes acts as a very powerful manure, producing such an increase in crops that farmers have been induced to use it to the exclusion of other manures, until the soil is reduced to the verge of sterility.

In attempting to even briefly explain a few of the many sided effects of lime on the soil, it is well to have in mind the fact that lime acts mechanically as well as chemically.

Mechanical Action of Lime. That lime should be able to stiffen a light soil, and lighten a stiff one, would at first seem almost paradoxical, and yet, certain well recognized properties for which lime is extensively used in the arts, may at least enable us to imagine how this may be true. "A very little attention to the way lime acts in mortar will make this assumption clear. If a thick, smooth paste of slacked lime be spread thinly upon the surface of a stone, or upon a piece of wood, and left there to dry, it will be found that the film of dried lime adheres to the smooth surface with great tenacity; and since in the process of drying a good part of the lime has changed to the state of a carbonate, it can not even be readily washed away. A familiar example of this adhesion is seen in ordinary whitewashing. It is essential to the success of this experiment that the layer of lime should be thin; otherwise, it might crumble upon itself in drying. In case the paste be

spread upon a porous solid, such as a brick for example, instead of wood or stone, it will be noticed that the lime adheres to it more strongly than to the smooth surface, since some part of the layer has struck root, as it were, in the pores; and in case dry loam were taken instead of brick, the adherence would doubtless be stronger.

"Now, mortar is nothing more than lime paste, into which so many little stones (grains of sand, that is to say) have been put, that no more than a thin layer of lime shall be in contact with each one of these stones. But when a field is dressed with lime, the lime paste formed by the union of the lime and water must adhere to the particles of the soil in a manner analogous to that now in question, and physical character of the soil must be very much altered by this adherence. The power of the soil to lift water by capillary action will be changed, and in some cases it will be very much improved, while in other cases it will be diminished." *

As will be pointed out presently, lime has also the power to etch or corrode, the very hardest of the soil particles, and so, together with its own substance to add to the fine earth for filling in among the larger particles. A very striking example of the compacting or binding power of lime is to be found in the "hard pan" that is to be found some distance from the surface of certain soils. In the light loose sandy soils deficient in lime it is something in the nature of a hard pan that is needed.

In view of the above it may not be so hard to understand how lime may make a light soil more compact; but how does it make a stiff easily puddled clay soil lighter and easier to work? Again we shall have to refer to certain well known properties of lime. The stiff easily puddled, and often almost unworkable clay soils always contain a large amount of extremely, finely divided clay particles so fine, in fact, that they will remain a long time suspended in water. This accounts

* Agriculture, Storer.

for the long continued muddiness of certain rivers and the smaller streams. When such streams flow into the ocean or into certain lakes containing considerable quantities of certain saline matters in solution, they quickly become clear. A small quantity of lime is very efficient in clearing muddy water, as may be shown by shaking up a small quantity of fine clay with water, noting how long the water will remain cloudy, and then repeating the experiment after adding a small quantity of lime water. The lime causes the fine clay particles to floculate or coagulate, forming particles that are too large to remain in suspension, and so, quickly fall to the bottom, leaving the liquid clear. The point not to be overlooked is that as a result of the action of the lime these extremely fine clay particles, which cause the puddling and other objectionable features of clay soils, are gathered into larger particles, thus making the soil more porous.

Again, clays shrink on drying, while lime does not. Every one has noticed the blocks or plates into which the bottom of a mud puddle will crack up on drying. These plates consist largely of clay, so the width of the cracks give some idea of the amount of shrinkage. The upper surface of the plates consist of the finest clay, which, being held longest in suspension, was deposited last; and proceeding downward through the plates there is more and more silt, fine sand, etc. The difference in the shinkage of these constituents is very nicely shown by the warping of the plates, resulting in a concave upper surface.

Now, lime does not shrink on drying, so when it is intimately mixed with clay, wet and allowed to dry, the minute films of clay surrounding the lime particles are warped and cracked in every direction ; in a word, the objectionable adhesive property of the clay is destroyed.

Any one can easily satisfy himself in regard to this very valuable effect of lime on stiff clay, by simply taking a handful of such clay, wetting and working it

thoroughly and then allowing it to dry, when, with difficulty, he may avoid pronouncing it "as hard as rock." But take another portion of the same clay (or grind up the same piece) mix with it a small quantity of lime, say one half of one per cent, and after wetting and mixing it throughly, allow this to dry. A mere touch will cause it to crumble to pieces—indeed, a very decided difference will be noticed while it is in the plastic state. There are other materials which have a somewhat similar effect on clays, but none of them are so efficient as lime. This granulated condition of clay soils, so easily accomplished by liming is not easily destroyed, but will last for years.

Much might be said in regard to this granulating effect of lime on stiff clays, as well as of its power to make light sandy soils more compact; indeed, if lime had no other use in agriculture, it would merit no mean place among the materials at the disposal of the farmer. But lime has other effects upon the soil, and these may be considered under the following heading:

Chemical Action of Lime. One of the most important changes brought about by the action of the lime in the soil is the decomposition of certain silicates. Among these may be mentioned the well known mineral feldspar, which may contain very considerable quantities of potash, but which is beyond the reach of plants until the feldspar is completely broken down (to form ordinary clay) when the potash becomes available. A careful examination of clay soils will often show them to contain small fragments of undecomposed feldspar, and lime, by hastening the decomposition of these fragments increases the amount of available potash.

But the action of lime on inert soil particles is not limited to undecomposed feldspar, as lime (more especially in the caustic form) is quite capable of attacking even the most refractory silicates and as a result of its action there is a strong tendency towards the formation of a class of less insoluble silicates. These contain

silica, alumina, water (in combination) and certain alkaline substances, such as lime, soda, potash or ammonia. But without stopping to consider more carefully their composition, or the manner in which lime aids in their formation (which is extremely complex) we may profitably pass to the properties of these bodies which have been carefully studied, are well understood and are of the greatest importance from an agricultural standpoint.

It is well known that these materials, although insoluble in water, are available to plants; that they are readily soluble in even dilute hydrochloric (muriatic) acid, and may be extracted from a quantity of soil by means of this reagent; that when so obtained from the soil, or when prepared artificially (for this may be easily done) they possess the property of absorbing or "fixing" lime, soda, potash and ammonia, while the soil from which they are removed possessses such properties to but a very limited extent.

One of the most remarkable properties of these constituents of the soil is the order in which they seem to prefer the bases mentioned. They act as though they fully realized the fact that ammonia is more expensive than potash, potash than soda, etc., for if only lime is presented they will combine with it, but in the presence of soda they will let go of the lime to take up the soda; and soda or lime to combine with potash, while they would release either potash, soda or lime to combine with ammonia.

Clay soils contain these silicates in largest quantities; sandy soils in the smallest quantity, and every one is familiar with the difference in the capacity of theset wo classes of soils to retain the alkaline substances referred to. So, limeby hastening the decomposition of the refractory silicates, not only converts their valuable constituents (potash and phosphoric acid) the more quickly into available form, but it also promotes the formation of these less insoluble silicates, upon which so largely depends the

power of the soil to retain certain constituents of plant food added to the soil as fertilizers.

Lime on Acid Soils. We have frequently had to refer to the two classes of substances, "acids" and "bases." The acids are generally recognized as having a sour taste, turning blue litmus paper red, etc., while the alkaline or basic substances have properties just the reverse of the acids, they turn red litmus paper blue etc. When an acids is brought in contact with a base, the acid properties of the one substance and the basic properties of the other disappear and a neutral substance (possessing neither acid or basic properties) is formed. It is because lime is a strongly basic subtsances that it so readily unites with phosphoric acid, sulphuric acid, hydrochloric acid, nitric acid, etc., to form the neutral substances, phosphate of lime, sulphate of lime nitrate of lime etc.

We have already had occasion so often to speak of the effect of lime on "acid" soils, that little need be added. Some basic material must be present to neutralize the nitric and other acids formed in the course of the decomposition of the organic matter in the soil. Undue acidity is detrimental, not only to the nitrifying organisms, but also to most cultivated plants.

That this acid condition may exist in the soils of poorly drained old meadows, rich in organic matter, has long been known, and the beneficial effect of an application of lime in such cases is also well established, as it is often quickly observable in the disappearance of the sorrel and other weeds and coarse grasses (which alone could thrive on an acid soil) and the more thrifty conditton of the true grasses. But excessive acidity is not limited to old meadows, or poorly drained soils. It may exist in upland soils, and other naturally well drained soils. Ruffin refers again and again to the value of lime (marl) in correcting acidity of soils that were naturally well drained. Wheeler has given this phase of the subject a great deal of attention and has shown that in the eastern part of the country acid soils are very much

more abundant than has generally been supposed.

In connection with the soil investigations at this Station, quite a number of acid soils have been found in various parts of the state, and undue acidity doubtless exists in soils where it has never been suspected, the indifferent results which alone need be expected in such cases being attributed to other causes.

Tests for Acidity in Soils. Some plants, for example clover and timothy, are very susceptible to this acid condition of the soil, which doubtless often contributes largely to the difficulty of obtaining or maintaining a stand of these plants, certain coarse vegetation being less susceptible and easily crowding out everything else. So, an indication as to the condition of the soil in this respect may often be obtained by noting the character of the vegetation. Of course, some crop known not to thrive in an acid soil might be grown with and without lime, and for this purpose beets are often recommended, but lime may act in so many other ways besides correcting acidity, that any difference in favor of the limed portion may be due to any one or even all of the other effects of lime on the soil.

One of the oldest, simplest and, in experienced hands, one of the most reliable tests is that involving the use of blue litmus paper. It is carried out as follows: "A table spoon full or more of the soil is placed in a tumbler or cup, and moistened with sufficient water to make the mass about the consistency of thick paste. It is best to allow it to stand for fifteen or twenty minutes before making the test, though it may be made at once. With a knife blade part the soil and introduce one end of a slip of blue litmus paper, which may conveniently be about one-half three quarters of an inch wide and two inches long; press the soil about the paper and after two to five minutes remove the paper without tearing it, rinse off the adhering soil with water, and note whether it still remains a blue tint, or has become positively red If the soil has a marked reddish tint, as is sometimes

the case, it may be better to bring but one side of the paper in contact with it, and if a red color comes through to the other side, it may be concluded that the soil is acid. In all cases, care must be taken not to handle the end of the paper which is used for making the test, since the touch of the fingers may redden it, and thus one might be deceived."*

The remedy for an acid soil is lime. It might be inferred from what was said in regard to alkaline or basic substances that the power to correct acidity is limited to the caustic lime, or at most to slacked lime, and that in as much as both these forms are quickly converted (by the carbonic acid of the soil water) into the neutral corbonate of lime, that the power to correct acidity would sooner or later be lost, but fortunately this is not the case. Carbonic acid is a very weak acid, and the lime will let go of it to combine with any other acid formed in the soil. Acetic acid is one of the long list of acid substances formed in the course of the decomposition of organic matter in the soil, and contributing to an acid condition of the soil, and any one may easily satisfy himself as to the ability of acetic acid to replace carbonic acid in the carbonate of lime by simply pouring a little vinegar on a piece of limestone. So when quick lime (burnt lime) is applied to the soil, it unites with the soil water to form slacked lime, which being somewhat soluble in water becomes distributed throughout the soil. If the lime remained in this form it would be quickly leached from the soil, and it would be quite as objectionable to the plants and the nitrifying bacteria as the acidity it is intended to correct; in fact, nitrification is practically suspended for a time after an application of quick lime,—another reason for applying lime in the fall. But sooner or later the slacked lime finds in the soil water the necessary carbonic acid to convert it into the carbonate of lime, which being less soluble is less likely to be leached

* Wheeler —Rhode Island Ex. Siation Bulletin.

from the soil, and being a neutral substance cannot be objectionable to plants or to the microorganisms of the soil, but which stands ready, as occasion may demand, to act as a strong base in correcting the very undesirable acid condition.

Lime on Soils Containing an Excess of Magnesia. The splendid work of Leow & May * shows there is yet another important use for lime on the farm in that it will correct the noxious effect of an excess of magnesia in the soil. All soils contain an abundance of magnesia for the immediate demands of plants, and it appears that a soil may contain enough magnesia to have a very injurious effect on most crops.

The amount of magnesia varies widely in different soils and even among the very best soils, so the amount that may or may not prove injurious can not be stated in terms of magnesia alone. It is the amount of magnesia as compared with the amount of lime or the ratio of these constituents in the soil that determines whether or not the magnesia may be injurious.

From the work referred to, it would appear that if a soil contains an excess of magnesia, the best results need not be expected; that if the magnesia is largely in excess the case is still worse and that it is when the lime and magnesia are present in about the proportion of 7 to 4 that the best results are obtained.

Plants thrive on soils containing a much larger proportion of lime, but such soils would doubtless be improved by bringing the ratio nearer to that just mentioned, and for this purpose some of the crude potash salts might be used to advantage, for they would not only raise the content of magnesia, but the chlorides would (as already explained) remove a part of the lime. If on the other hand the soil contains an excess of magnesia, the crude potash salts can only aggravate the trouble. We have already given one reason why in making heavy applications of the crude potash salts,

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we should "make sure that the soil is not deficient in lime." Now we have another reason; we should make doubly sure.

That lime is the remedy for an excess of magnesia should hardly need to be stated, and yet a word in regard to the kind or quality of lime to be used may be in order. Manifestly lime made from 30 per cent to 40 per cent magnesian limestone, would hardly be the kind to use. Not only would such lime or mixture of lime and magnesia do little to correct the undesirable proportion already existing in the soil, but it is possible that when applied in this form the magnesia may exert a greater influence than the lime, because compounds of magnesia are, as a rule, more soluble than the corresponding compounds of lime.

The solubility (or availability) of the various forms in which the lime and magnesia exist in the soil, is a matter of much importance, and in the above paragraphs we have referred only to the *available* lime and the *available* magnesia, for evidently the magnesia that is locked up in a refractory silicate, or other insoluble form, can do no more harm than the potash in similar forms can do good. The total magnesia in the soil might be three or four times as great as the total lime and yet there might be more available lime than available magnesia; or just the reserve might be true.

The only way to tell whether or not a limestone contains too much magnesia is to analyze it and the only way to tell whether or not a soil contains too much magnesia is to analyze it. Now we are fully aware that there are those who never miss a chance to belittle the analysis of soils—but, then, it is often so much easier to dismiss a subject with a sneer than to discuss it intelligently. This station believes in analyzing the soil and has for a number of years been engaged in a systematic examination of the soils of the state. The work has not progressed as rapidly as could be desired, but it has gone far enough to show that in the northern

half of the state there is no lack of soils that are not only decidedly acid but in which the proportion of lime to magnesia might be improved, and there is doubtless no lack of farmers who are experiencing no little trouble in their efforts to overcome such conditions of the soil by the application of various fertilizers, and who, on failing to receive reasonable returns, feel justified in condemning the fertilizers for failing to accomplish that for which as a matter of fact, they were never intended, and while the material needed, and in some cases the only material needed was lime.

Caution. Notwithstanding all the valuable functions of lime as above enumerated, i.e., in improving the mechanical condition of the soil, in correcting acidity, in promoting nitrification, in promoting the decomposition of the refractory silicates and organic matter, thus making the plant food contained in such materials the more quickly available, in correcting the noxious effect of an excess of magnesia, etc., lime must be regarded as a "stimulant," or at best as a "tonic." Lime may be relied upon to correct many abnormal or "diseased" conditions of the soil, and in considering the changes which take place in the many forms of nitrogen, phosphoric acid and potash applied to the soil as fertilizers before the same can be appropriated by plants, we were continualy confronted with the effect of lime. The chlorides, which are objectionable to certain crops and which are added as chloride of potash or with the crude potash salts, are removed from the soil as chloride of lime, while the potash is retained in the soil largely by the more soluble silicates, the formation of which is promoted by the use of lime. If lime is present in normal quantities the soluble phosphates unite with it to form reverted phosphate of lime rather than the less soluble phosphates of iron or alumina. When nitrogen is applied as sulphate of ammonia, the latter is converted into sulphate of lime and nitrate of lime, while the nitrogen contained in the organic matter in

the soil, and that added to the soil in the various organic materials is doubtless for the most part sooner or later converted into the nitrate of lime. It is almost remarkable that the soil should be able to convert all these various materials into just such forms as those already existing in a normal soil, and it is certainly remarkable that in these transformations lime should play such an important part.

By hastening the decomposition of refractory silicates, inert organic matter, etc., lime enables the farmer to draw upon his soil's latent or reserve fertility. In this respect lime acts like a true stimulant, and the danger is much the same as with other stimulants,—it is so likely to come to be regarded as a sort of panacea and to be used on all occasions to the exclusion of other fertilizers and manures until the reserve fertility, or the best of it, being exhausted the soil is reduced to the verge of sterility.

The best time to apply lime is in the fall and after *a well fertilized* green crop such as cow peas or clover has been plowed under; indeed a heavy green crop should never be plowed under without liming unless the soil is known to contain an abundance of lime.